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THE TEXTILE FIBERS

WORKS OF

J. MERRITT MATTHEWS

PUBLISHED BY

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Application of Dyestuffs to Textiles, Paper, Leather and other Materials

768 pages, 6 by 9, 303 figures.

The Textile Fibers

Their Physical, Microscopical, and Chemical Properties. Fourth Edition, Rewritten and Enlarged. 1053 pages, 6 by 9, 411 figures.

THE TEXTILE FIBERS

Their Physical, Microscopical and Chemical Properties

BY

The Late J. MERRITT MATTHEWS, Ph.D.

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FOURTH EDITION

Rewritten and Enlarged

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PREFACE TO THE FOURTH EDITION

Since the last edition of this volume of ten years ago there has been so much new matter appearing in the field of textile fibers that the author has been under the necessity of entirely rewriting and rearranging the book. In the present edition, therefore, the reader will find that a great deal of new matter has been introduced and the general plan of the book has been readjusted to meet the demands of a logical development of the subject.

The field of textile chemistry and the processing of textile fibers has taken on new proportions during the past ten years. To mention only one branch of the subject, the artificial silk industry, for example, has expanded until at the present time more artificial silk is made than is obtained as a natural product from the silkworm. The use of mercerised cotton has become an established factor in the cotton industry and has become stabilised into a standard process. The World War caused much research into the possibilities of utilising other fibers than those normally employed, and we find a great variety of experimenting, such as in the spinning of the so-called "staple" fiber yarns. Some of these sporadic attempts have passed out with the necessity of their use, while others have shown themselves to be of sufficient worth to remain in the general body of textile products.

The fact that several reprintings were called for in the third edition of this book has encouraged the author to feel that his attempt to bring together such a large mass of scientific and technical data concerning the textile fibers has been more or less appreciated by those interested in the fiber industries. He has scoured the literature of this country and Europe rather thoroughly in the search for information, and anything of interest or value he has not hesitated to take and has endeavored to fit it in its proper place in this volume. The patent literature has also been thoroughly digested, though it has been the author's experience that in this province great care must be exercised so as not to distort in one direction or the other the technical values in a patent.

Believing that proper illustration of technical books is of extreme importance, the author has been at great pains to select from his own

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rather large collection of fiber micrographs those which possess some interest in relation to the present subject matter. Furthermore he has picked out wherever he could find them fiber micrographs appearing in the general technical literature and has endeavored to give full credit wherever possible to the original source. In addition to the fiber micrographs endeavor has been made further to illustrate the text with suitable figures of apparatus and machinery so that the reader may better visualise the descriptions of the processes involved. When the eye can see a picture the interest is more easily aroused and the attention is more readily held, and the fact that is seeking to be elucidated is more clearly presented to the understanding.

The field of textile chemistry as a profession is growing, and it is in the hope of furthering the dignity of this province of science that the author presents this present volume to those whose work is related to this branch of the subject, whether in the scientific, the technical, or the commercial aspect. Textile fibers extend into many lines of our industrial and commercial activity, and knowing that the great majority of his readers are neither chemists nor scientists, the author has been careful to avoid a mere scientific presentation of the subject matter and has endeavored to express himself in a manner that is clear even to those without a scientific education.

J. Merritt Matthews.

New York City, 1923.

PREFACE TO THE FIRST EDITION

The present book, it is hoped, will be of assistance to both the practical operator in textiles and the student of textile subjects. It has been the outgrowth of a number of years of experience both in the teaching of textile chemistry and in the practical observation in the many mill problems which have come under the notice of the author in the practice of his profession.

The textile fibers form the raw materials for many of our greatest industries, and hence it is of importance that the facts concerning them should be systematised into some form of scientific knowledge. The author has attempted, however, not to allow the purely scientific phase of the subject to overbalance the practical bearing of such knowledge on the everyday problems of industry.

Heretofore, the literature on the textile fibers has been chiefly confined to a chapter or two in general treatises on dyeing or other textile subjects, or to specialised books such as those of Höhnel, Hanausek and Wiesner on the microscopy of the fibers. It has been the author's endeavor, in the present volume, to bring together, as far as possible, all of the material available for the study of the textile fibers. Such material is as yet incomplete and rather poorly organised at its best; but it is hoped that this volume may prove a stimulus along the several lines of research which are available in this field. Unfortunately, the subject of the textile fibers has been lamentably neglected by chemists, although there is abundant indication that a fertile field of research is open to them in this direction, and such work would have not only a scientific value, but would also be of great industrial worth. There is, as yet, relatively little known concerning the chemical constituents of the fibers, and the manner in which the varying chemical conditions of bleaching and dyeing and other chemical treatments affect the composition and properties of these constituents. The action of various chemical agents on the fiber as an individual has been but very imperfectly studied. More work has been done in the microscopical field concerning the properties of the fibers; but even here the knowledge is very incomplete and disjointed, and especial attention is drawn to the fact that there is yet a large amount of work to be done in the microchemistry of the subject.

The author has endeavored to emphasise throughout this volume the importance of the study of the fiber as an individual, for in many cases it is misleading to assume that the behavior of the individual fiber is identical with that of a large mass of fibers in the form of yarn or cloth. In the latter case, the difference in physical condition and the action of mechanical forces have an important influence. By going back to the study of the individual fiber as a basis, many explanations can be given which could not otherwise be discovered.

It is hoped that this book may afford instruction both to the manufacturer and to the student; assisting the former in solving some of the many practical problems constantly occurring in the manufacture of textiles, and urging the latter on to an increased effort in the scientific development of the subject.

J. Merritt Matthews.

New York City, 1913.

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THE TEXTILE FIBERS

CHAPTER I

GENERAL CLASSIFICATION

1. Fibers Chiefly Used for Textiles.—In order to be serviceable in a textile fabric, a fiber must possess sufficient length to be woven and a physical structure which will permit of several fibers being spun together, thereby yielding a continuous thread of considerable tensile strength and pliability. Although there are several fibers, such as spun glass, asbestos, various grasses, etc., which are used for the manufacture of textiles in peculiar and rare instances, yet the fibers which are employed to the greatest extent and which exhibit the most satisfactory qualities are wool, silk, cotton, and linen. All of these possess an organised structure, and are the products of a natural growth in life processes.

2. Historical.—The study of the various textile fibers employed by different nations throughout the ages is an excellent commentary on the progress of civilisation and affords a good idea of the industrial life and economic condition of the peoples concerned. It is an interesting fact that most of the commercial fibers that are in use at the present time were also prominent in the industrial life of past ages. Cotton, flax and hemp were apparently known and utilised in past ages in much the same manner as they are to-day, and we find them well distributed among the various nations of the world. The animal fibers of wool and various hairs were also utilised for the making of fabrics and other materials in the earliest ages. Silk seems to have been more recently recognised and to have been developed for a long period in one nation exclusively, namely, China. The use of flax or linen perhaps dates back to a greater antiquity than that of any other fiber, or at least it is the fiber of which we possess the most ancient records. The cultivation of flax and the utilisation of its fiber goes back to the Stone Age of Europe. Remnants of flax fabrics have been found in the remains of the Swiss Lake Dwellers, who were apparently a people contemporaneous with the mammoth in Europe. Well-authenticated specimens of these fabrics are to be found

in our present museums. Four or five thousand years later the Egyptians are known to have cultivated flax also, and in fact the species of plant so utilised appears to be almost identical with the common flax plant of the present day.

The culture and manufacture of flax as well as the spinning and weaving of the yarn is shown in the pictorial carvings on the walls of Egyptian palaces, temples and tombs. Also linen fabrics probably 4500 years old have been found in Egyptian tombs, employed as mummy cloths, and these fabrics show a wide variety of structures, from very fine delicate cloth to coarse sail cloth or canvas. As much as 300 yds. of cloth was used to wrap one mummy; consequently these mummy cloths, which are still in a fine state of preservation, have been handed down to us in considerable quantity and may be seen in almost any museum. Much of the cloth was evidently undyed, but a considerable part was colored, chiefly in red, yellow and purple.

From the historical records of the Babylonians it is also apparent that their textile industries were in a high state of development and they were well acquainted with the use of flax, cotton and wool. The early Greeks were evidently more familiar with wool as a textile than with either linen or cotton, though later these were brought in from other countries. The same is also true of the early Romans.

In ancient America, flax and hemp were both known to the Aztecs of Mexico, and cotton was also known to the ancient Incas of South America. In ancient India, cotton seems to have been the national textile fiber, and the expert use of this fiber in the weaving of fine and delicate fabrics became famous, if we can believe the extreme praise of them to be met with in poetry and legend. The Hindoo muslins were said to be so fine that when laid on the grass and wet with the dew they became invisible. It is not possible for us to say just how far back in history the use of cotton was first known in India, but we have records of 800 B.C., which indicate that the cotton industry at that time was well known and long established. Cotton was not introduced into Greece until about 200 B.C.

The use of hemp among the ancients was apparently very limited; the hemp plant grows wild throughout India, but it was regarded more as a source of a drug (hasheesh) than as a fiber plant. We find no mention of hemp in the Bible, and it is very seldom referred to by other writers of antiquity. In the Sanskrit Institutes of Menu, however, we find mention of *sana* as a fiber from which certain sacrificial threads were prepared. This *sana* has been supposed to refer to Sunn Hemp, which is one of the commercial fibers even of the present time in India. Hemp was used by the Scythians in 500 B.C. for cordage, and apparently it was also known to the Chinese at a very early period.

One of the oldest fibers of Oriental nations was China grass or ramie. The utilisation of this fiber antedates the written records of history both in China and in India, and it may have been used in Egypt for mummy cloth contemporaneous with flax. This fiber was not known to the ancient Americans, but these people used the fiber from the agave (sisal hemp or henequen) for the making of cordage.[1]

3. Properties Required in a Textile Fiber.—The availability of a fiber for textile purposes must be considered with reference to its adaptation to the various operations and processes through which it is required to pass in the formation of a woven fabric. Preliminary to the operation of weaving (or other similar operation by which a fabric is made) it is neces-

[1] It is impossible to state what was the first fiber employed for textile purposes, and how it came to be used. Weaving seems to have existed long before writing; consequently it is hopeless to expect any historical record of the origins of textile fibers. Probably the use of fibers in weaving developed out of the ancient art of basket making. Many primitive races early discovered that the stems of plants could be twisted together to form a framework which could be used for many purposes, such as stockades to protect them from wild animals and enemies, rush huts to protect them from the inclemencies of the weather, baskets to hold and carry food, and various other materials. It may have been that through wear and the action of the weather a basket made from flax stems changed its nature and became a bag. The thoughtful savage, no doubt, discovered that by weathering the flax straw long lustrous fibers could be obtained, which could then be twisted together to form a thread or cord, and this could be interlaced to form a new material, cloth. Flax seems to be found in all remains of prehistoric people, and it is very likely that this was man's first textile fiber. Wool would probably be the next textile fiber that came into use, as primitive man long employed sheep skins as a garment, and it would be natural to expect that he would soon become aware of the possibilities of using the fiber independent of the skin. In the Middle Ages wool became the staple industry of England, and its importance is handed down in the legend of the "woolsack" in Parliament. It seems that Edward III did not wish his Parliament to forget that the country's prosperity depended on its commerce, of which wool was then the principal item, so he ordered that sacks of wool should be placed in the House of Lords. A Lord Chancellor evidently found that these sacks were comfortable to sit on, and in time the "woolsack" became the recognised seat of this official.

It is probable that cotton did not come into use as a textile fiber until long after both flax and wool. It was evidently first used in India thousands of years ago. Its introduction into European trade is of comparatively recent date, it being first imported and spun into yarn in the early part of the eighteenth century. At first it was used only as a filling yarn with a linen warp, and it was not until 1783 that the first all-cotton cloth was made in Lancashire.

The use of silk was discovered in historic times, being used at a very early period in Asia, and only came into Europe in the Middle Ages. At first it was used only as embroidery and decorative material, but ultimately was used for weaving.

During the World War the Germans fell back on the use of paper for the making of textile yarns. This, however, was not a very new invention, as paper yarns have long been used by the Japanese, and it is also probable that something similar was employed by the ancients. Wires of metal have also been used for weaving; threads of gold and silver having long been employed as decorative material in the weaving of cloth.

sary that a continuous thread or yarn be prepared from the fiber and for the manufacture of such a yarn certain qualities are necessary and certain others are desirable.

4. Tensile Strength.—Probably the most important quality is tensile strength, for if the individual fiber does not possess in itself considerable strength it will not be possible to make from it a yarn suitable for use in the arts. There are a number of fibers, especially among the vegetable class (such as those of the common milkweed, etc.), which might prove of considerable value but for their lack of sufficient tensile strength. The four fibers mentioned in a preceding paragraph as the most important are all characterised by a high tensile strength. Although dependent also on other qualities, the resistance of a fiber to use and wear is primarily dependent on its tensile strength.

5. Length of Fiber.—The second important quality which determines the usefulness of a textile fiber is its length. It is, of course, very easy to understand even without resort to technical explanations, that where a continuous thread is to be made up of a large number of individual elements, these elements must possess a considerable length with reference to their thickness, otherwise it would not be possible to make a thread that would hold together. In a general way and other conditions being equal, the strength of such a thread will be directly proportional to the length of the individual fiber elements employed. On this account a yarn composed of the long fibers of Sea Island cotton is much stronger than a similar yarn prepared from the relatively short fibers of upland cotton. The lowest economic limit in length for fibers to be employed for purposes of spinning is about 5 mm. Fibers of less length than this, however, are available for paper making. During the recent war, when suitable fibers were not available in Germany, processes were developed for the spinning of very short staples from waste and reworked materials.

6. Cohesiveness.—A third essential quality for a textile fiber is cohesiveness. By this is meant the property of the individual fibers cohering or holding on to one another when spun into a yarn. This is usually brought about by the surface of the fibers possessing a high degree of frictional resistance. The surface of wool, for instance, is quite rough and serrated by reason of the projecting edges of its epidermal scales, the same as the surface of a fish. These projections easily catch in one another, so that when several wool fibers are twisted together they offer considerable frictional resistance to being pulled apart. Cotton also possesses an irregular surface which manifests a high degree of friction and this is greatly accentuated by the occurrence of many twists in the fiber which interlock when several fibers are spun together, and thus prevent the elements of the yarn from slipping apart when subjected to strain. Linen (and other analogous vegetable fibers) has also a roughened surface, and

furthermore possesses knot-like formations throughout its length which, of course, greatly enhance the surface friction of the fiber. Silk, on the other hand, when considered as the purified fiber, has a comparatively smooth surface, and its cohesiveness when employed as a spun fiber, as in the case of waste silk, is chiefly due to its great length in proportion to its thickness which allows of the fiber elements of the yarn wrapping around one another a great number of times, giving rise in this manner to great frictional resistance. When silk is not employed as a spun fiber as in the case of thrown silk yarns, the individual elements of the yarn must be considered as practically continuous filaments. The lack of cohesiveness in many minor vegetable fibers, such as ramie and the several varieties of so-called vegetable silks, greatly reduces their otherwise practical value as spinning fibers. The latter fibers more especially possess very smooth surfaces, and consequently they slip over one another in a yarn and are easily pulled apart.

7. Pliability; Elasticity.—Another quality which is very essential to a satisfactory textile fiber is pliability, which permits of one fiber being easily wrapped around another in the spinning operation. The stiffer and more wiry the nature of a fiber, the less is it adapted to the purposes of textile use. The fibers of ordinary wool, for instance, are very pliable, and are employed in the production of a wide variety of fabrics for which a stiff wiry fiber, such as horsehair, would be entirely unsuitable. The pliability of a fiber also determines in great measure its elasticity and resiliency, qualities which are often of prime importance in the manufacture of textile fabrics. Lack of these properties will make the fiber and its resulting products brittle and unyielding, and hence greatly limit the field of its usefulness. Fibers of glass, for instance, however fine they may be prepared, have a very narrow range of utility.

8. Fineness of Staple.—Furthermore, a fiber must possess sufficient fineness of staple to be useful in the production of spun yarns. The principal fibers all have very small diameters and a large number of them can be twisted together to yield a fine thread. Other things being equal, the finer the staple of the fiber, the finer the yarn which can be produced from it. The coarse vegetable fibers, such as jute, hemp, sisal, etc., can only be used for textile purposes in the production of crude, low-grade fabrics; the chief uses of such fibers being for the manufacture of bagging, cordage, etc.

9. Uniformity of Staple.—Besides these more properly termed essential qualities, there are a number of others which more or less determine the value of a fiber for textile purposes. Uniformity of staple is a valuable property; by this is meant evenness in the length and diameter of the individual fibers. This enhances the spinning quality very much and aids in the production of an even thread. If in one variety of cotton, for

instance, the individual fibers vary widely in their length and diameter, its value will be much less than another variety in which these dimensions are more uniform. As both wool and cotton in their natural state show considerable variation in the size of the individual fibers, in order to heighten the quality of the yarns produced a process known as "combing" is utilised, whereby the longer fibers are separated from the shorter ones, and hence much greater uniformity in staple is obtained. The more uniform the length of the fibers, the more even, and hence stronger, will be the resulting yarn.

10. Porosity; Capillarity.—Another desirable quality for a textile fiber to possess is that of porosity or capillarity. By this is meant that the fiber should be capable of easily absorbing liquids and solutions and of permitting these thoroughly to permeate its substance.[1] This property is important as it allows of the dyeing, bleaching, and otherwise preparing the fibers by modifying their natural condition. Fibers that could not be dyed or bleached would have but a limited application in the manufacture of textiles.

11. Luster.—A further quality, which under certain conditions enhances the value of a textile fiber, is luster. Fibers possessing this quality to a marked degree, such as silk, mercerized cotton, and certain kinds of wool, are capable of producing a wide variety of beautiful effects. Luster, however, is not an essential quality in a fiber as regards usefulness; it is only an ornamental quality which adds to the beauty of the product.

12. Durability.—There are two other features which must also be considered with reference to the textile fibers as well as to any other manufactured article. The first of these is durability, by which is meant that the substance of which the fiber is composed must possess a degree of permanence which permits of its general use; it must be capable of withstanding the conditions of wear to which it may be reasonably subjected. The use of artificial silk (lustra-cellulose), for instance, is greatly limited by reason of the fact that this fiber becomes much weakened and is liable to undergo disintegration when moistened with water. The principal textile fibers are all very resistant to the ordinary conditions of wear, more so, in fact, than many of the raw materials used in the preparation of most manufactured articles.

13. Commercial Availability.—The second feature to which reference is made has principally an economic significance. In order to possess commercial value a fiber must be available in large quantity, and its supply must be more or less constant and readily marketed; it furthermore must

[1] Gaidukov (*Zeit. Farb. Ind.*, 1908, p. 251) has made an extensive study of various textile fibers by ultramicroscopic methods and has confirmed the opinion that the fibers are of a colloidal character. The ultramicrophotographs published by Zeiss & Co., in connection with this research, are very instructive and interesting.

be cheap. It is possible to use spider's silk, for example, as a textile fiber for certain purposes, but the supply of this material is small and uncertain, and there are many difficulties in the way of its production which would doubtless prevent it ever becoming a staple article of commerce. There are a large number of vegetable fibers which examination shows to possess many valuable properties for textile purposes, but the practical supply of which is so uncertain as to render them unworthy of commercial consideration.

14. Classification of Fibers by Origin.—Though textile fibers in general consist of a wide range of materials, for convenience in study they may be

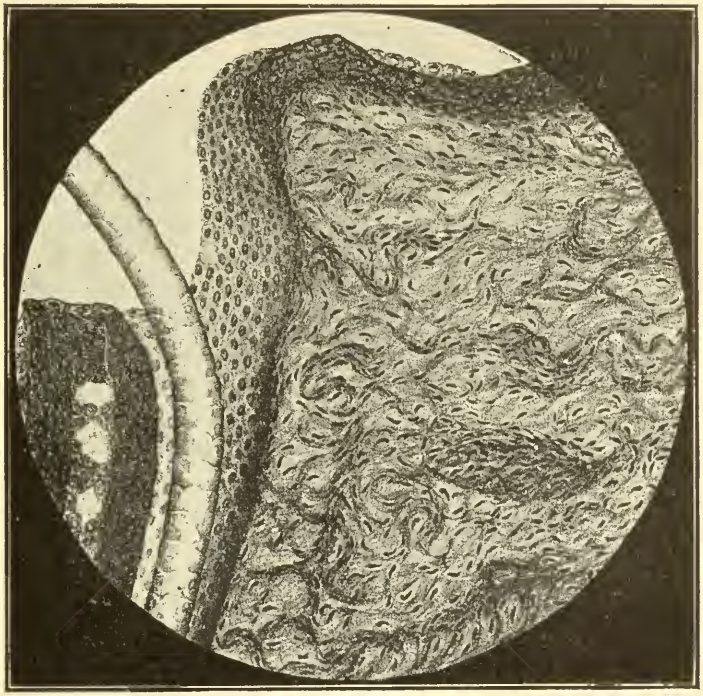


FIG. 1.—Wool Fiber Emerging from Skin Tissue.

divided into four distinct classes, as follows: (*a*) animal fibers, (*b*) vegetable fibers, (*c*) mineral fibers, (*d*) artificial fibers. According to a very complete compilation of M. Bernardin in his *Nomenclature uselle des fibers textiles*, the number of plant fibers used by the human species is more than 550 and perhaps about 700. Calculating in addition thereto the mineral fibers (asbestos and kindred substances) as well as the various packing materials, spun fibers, brush materials, and animal hairs, and silk, the number of single substances would probably amount to 1000, if not more.

These raw materials can occur in different forms, and many of them are important. Sheep's wool, for instance, is known in as many as 50 different varieties. It is clear that the various characteristics of all these forms would be very difficult to delineate and to differentiate from each other. The solution of such numerous questions as would be raised by the comparative investigation of so many objects would necessitate the accumulation of a large mass of unimportant details and divert the attention of the observer from the main points. In fact most of the exotic fibers are unimportant or are only employed in the localities in which they are grown.

15. Animal and Vegetable Fibers.—According to their origin, we may divide the principal fibers into two general classes, those derived from animal and those derived from vegetable life. The former includes wool and silk, and the latter cotton and linen.

Animal fibers are essentially nitrogenous substances (protein matter), and in some cases contain sulfur. Protein matter is of the character of albumen, and forms one of the principal ingredients of animal tissues. It is essentially nitrogenous in composition and is especially characterised by the peculiar empyreumatic odor evolved when it is burned. One of the readiest and most conclusive tests, in fact, which may be used to distinguish between an animal and a vegetable fiber is to notice the odor evolved on burning in the air. With regard to their physical condition, it may be said that the proteids composing the animal fibers are essentially of a *colloidal* nature; that is, they resemble a solidified jelly in condition. This property of the fibers may be used, to a great extent, to explain their action with solutions of dyestuffs and metallic salts, in which the theory of solid solution, adsorption, and osmosis comes into play. Alkalies readily attack the animal fibers, causing them to be dissolved, but they withstand the action of mineral acids to a considerable degree. Contrary to the vegetable fibers, they are readily injured if exposed to elevated temperatures.

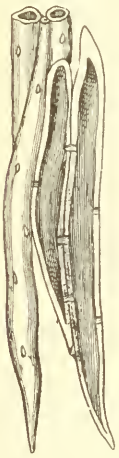


FIG. 2.—Cells of Wood Tissue. (×500.)

16. Vegetable Fibers.—These consist of plant cells usually rather simple in structure and forming an integral part of the plant itself. Plant cells are of different character and size depending on the part of the plant in which they occur and the office or function they perform in the development of the plant tissue. These cells consist of tubes generally between 0.001 in. and 0.002 in. in diameter; their ends are usually pointed and in their arrangement overlap one another. (See Fig. 2.) In the fibrous layers occurring in plants these cells are sufficiently long and so interlaced as to give a fiber of considerable

strength, whereas in plain woody tissue the cells are short and properly speaking yield no fiber of sufficient strength or length to be used for textile purposes. In monocotyledons, according to Dr. Morris, the fibrous cells are found built up with vessels into a composite structure known as fibrovascular bundles; these bundles occur in the leaves and stems, but not in the outer bark of plants (see Fig. 3), and are usually found imbedded in a soft cellular tissue known as *parenchyma*. The vegetable fibers are capable of withstanding rather high temperatures, and are not weakened or disintegrated by the action of dilute alkalies. They consist essentially of cellulose, which may be in a very pure form or be mixed with its various alteration products. In some cases the fiber consists of some cellulose derivative obtained by chemical means, such, for instance, as mercerised cotton. Concentrated alkalies produce alteration products with the vegetable fibers. Free sulfuric or hydrochloric acid, even if only moderately strong, will quickly attack the fiber, disintegrating its organic structure and forming hydrolysed products. Nitric acid, on the other hand, forms nitrated celluloses (the so-called nitro-celluloses) and various oxidation derivatives.

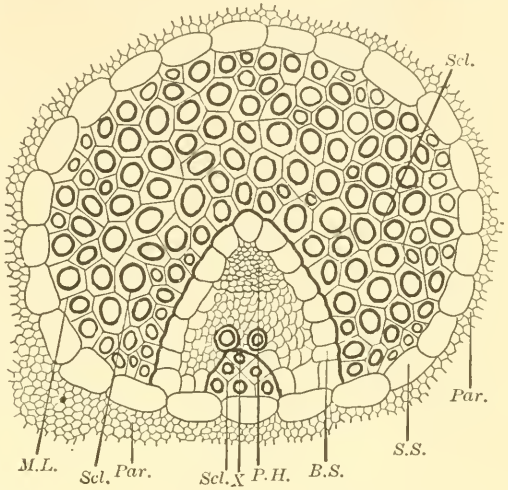


FIG. 3.—Section of Fibrous Plant Cells (Sisal Hemp). (×300.) *Par.*, cellular parenchyma; *S.S.*, starch layer; *Scl.*, sclerenchyma; *M.L.*, middle lamella; *B.S.*, bundle sheath; *X*, xylem or wood cells; *P.H.*, phloëm or bast cells. (After Morris.)

It is generally considered that the animal fibers have a lower conductivity for heat than have the vegetable fibers, and in consequence fabrics made from wool and silk are warmer than those made from cotton and linen. From actual tests, however, it would seem that this quality was due more to the structure of the fabric than to the character of the fiber.

According to Dietz the specific heats of the various fibers are as follows:

Raw silk	0.331
Boiled-off silk	0.331
Worsted yarn	0.326
Artificial silk	0.324
Linen	0.321
Cotton	0.319

Jute	0.324
Kapok	0.324
Hemp	0.323
Manila hemp	0.322
Sisal hemp	0.317
Asbestos	0.251
Glass wool	0.157
Straw	0.325
Soda wood pulp	0.323
Sulfite wood pulp	0.319

Count Rumford made some interesting experiments relative to the "heat-retaining value" of various clothing materials. He heated a large thermometer to a given temperature and then ascertained the length of time required for the thermometer to fall to a given point when surrounded with the various materials experimented upon. The times taken by the thermometer in falling from 70° to 10° Réaumur, when surrounded with various substances, were as follows:

	Seconds.
Air	576
Raw silk	1284
Sheep's wool	118
Cotton	1046
Fine lint	1032
Beaver's fur	1296
Hare's fur	1315
Eiderdown	1305

In another series of experiments, however, using the same materials differently arranged, very different results were obtained:

	Seconds.
Sheep's wool, loosely arranged	1118
Woolen thread, wound round bulb	934
Cotton, loose	1046
Cotton thread, wound round bulb	852
Lint, loose	1032
Linen thread, wound round bulb	873
Linen cloth, ditto	786

From these experiments, Rumford showed that the heat-retaining value of clothing depends more on its texture than on its actual material. For further consideration of this subject, see Mattieu Williams' book on *The Philosophy of Clothing.*

17. Mineral Fibers.—The mineral fibers are of rather rare occurrence in the textile industry as compared with the extensive use of the preceding classes of fibers. The mineral fiber asbestos, however, is finding an increased use for certain purposes, and consequently deserves to be classified and considered in a comprehensive study of the textile fibers. Asbestos

is practically the only natural mineral fiber with which we are acquainted, the other mineral fibers, such as spun glass and mineral wool or slag fiber, are all artificial fibers, and are better considered under that class.

18. The Artificial Fibers.—These may be divided into two groups: (*a*) those of mineral origin and (*b*) those of animal or vegetable origin. In the first division may be classed such fibers as spun glass, metallic threads, and slag wool; in the second division may be put the various artificial silks, such as lustra-cellulose and gelatine silk.

19. Spun Glass.—Fibers of spun glass are prepared by drawing out molten glass in the form of very fine threads. It is said that such threads can be drawn out so fine that it takes about 1400 miles of the fiber to weigh 1 lb. Colored glasses may be used to give rise to variously colored threads. Owing to its brittle nature and lack of elasticity, spun glass receives a very limited application, it being made into various ornamental objects, and sometimes into cravats. Though fabrics composed entirely of glass are rare, yet colored glass threads are somewhat used for the weft in silk materials for the purpose of producing novel effects, as the glass gives the fabric great luster and stiffness. A variety of spun glass known as *glass wool* is used to some extent in the chemical laboratory as a filtering medium for liquids which would destroy ordinary filter paper. Glass wool is curly, this property being given to it by drawing out the glass thread from two pieces of glass of different degrees of hardness; and by unequal contraction on cooling, this double thread acquires a set curl.

Spinning glass for commercial uses is an important new industry which has been developed in Venice within the past several years. The spun glass is marketed in three forms—hanks of spun glass thread of straight fiber called *Cotone di Vetro* (glass cotton), masses of spun glass curled fiber called *Lano di Vetro* (glass wool), and either of the above qualities pressed into sheets or pads from $\frac{1}{4}$ to $\frac{1}{2}$ in. in thickness that resemble white felt pads. At present the principal use made of this product is for insulation, and especially for making separators for accumulators of electricity; but the glass wool would serve admirably for making artificial hair, wigs, perukes, dolls' hair, Santa Claus beards, and other purposes, and in the pad form it serves as a hygienic filter.

The processes of manufacture are simple. Solid glass rods, about 2 ft. 6 ins. long and of the thickness of a lead pencil, are made of pure soda glass that contains no adulteration of lead or other metal. The absence of lead and adulterations gives the quality of perfect flexibility to the fiber. On a simple desk is mounted a Bunsen burner or gas flame and blowpipe. By the side of the desk is mounted an ordinary bicycle wheel, minus the rubber tire, that revolves rapidly and regularly at rhythmic speed under power furnished by a small electric motor. A girl sits at the desk, melts the end of the glass rod in the flame of the gas burner,

draws it to a thread and throws the thread around the wheel. If the thread breaks, she must repeat the process; if not, she slowly revolves the end of the rod in the constant flame, and it is automatically spun to a very thin filament. The hank of thread on the wheel, when it has assumed the dimensions of a bicycle tire, is taken off. Separated with the fingers, it curls and fluffs out like wool if the thread is sufficiently fine. It is packed in the hank as glass cotton, in the fluff as glass wool, and in the compressed form as glass wool or cotton according to the fineness of the fiber. The cheaper grades of spun glass formerly came from Germany; it is claimed that the Italian article is superior.

20. Metallic Threads.—Metal yarns or threads consisting of various metals drawn out into filaments are used in decorative fabrics. Gold, silver, copper, and various alloys are used for this purpose, the metals being heated to redness or until they are in a softened condition. At the present time metallic threads are largely imitated by coating linen yarns with a thin film of gold or silver. Threads of pure gold are seldom made; what is known as *pure-gold* thread is a fine silver wire covered with a thin layer of gold. Silver thread is sometimes made with a core of copper and a layer of silver. *Lyon's gold thread* consists of copper faced with gold. Metallic threads are usually made into a flattened or band-like form by rolling. By twisting with silk or woolen yarns, the so-called *brilliant yarns* are made. The Cyprian gold thread of old embroideries consists of a linen or silk thread around which is twisted a cover of gilded catgut.

Bayko metal yarn is a textile product recently introduced. It consists of a core of cotton, silk, or other thread, which is coated with a solution of cellulose acetate containing in suspension finely divided particles of metals. The yarn is thus given a metallic coating, yet furnishes a durable and flexible thread. Microscopical examination of this yarn shows each filament to consist of a core or nucleus, and an enveloping layer. The core is usually a twofold cotton thread, while the envelope is a colorless to pale yellow substance. The average cross-section of a single filament is 0.0372 sq. mm. The cross-section of the envelope is 0.0133 sq. mm., or 35.8 percent of the total. The metric size averaged 29.6; the thickness of the filament 0.191 mm.; the tensile strength averaged 462 gms., and the elasticity 4.9 percent.

Another process of metallising yarn consists in coating the yarn with a solution containing a metallic powder and an adhesive liquid. Casein has been used, but the adhesion is not durable. Others have preferred gelatin which adheres to the yarn more firmly, but is open to the objection of being very hygroscopic, causing mold. Attempts have been made to protect the metallised yarn against the action of moisture by applying a transparent solution of celluloid or collodion, but this gives the

yarn a lustrous appearance different from that of metal. Edmond Dhunnausen has found after repeated experiments that casein glue adheres firmly when the yarn has been previously treated with a mixture of gelatine and a powder insoluble in that material. The casein glue is loaded with the metallic powder to give the desired appearance. The yarn is passed through a bath consisting of:

Gelatine	25 parts
Metallic powder	25 "
Water	25 "

After drying for about twenty minutes the yarn is passed through a bath made up as follows:

Casein	15 parts
Borax	5 "
Water	80 "
Metallic powder	30 "

After drying a second time very rapidly the yarn is passed through a second bath of the same composition. The weight of the metallic powder used varies according to the specific gravity and the nature of the material. The effect can be varied by adding different colors to the last bath.

Probably the most successful method for metallising yarns or fabrics, and for the making of metallic prints, is the use of Bakelite (a formaldehyde condensation product of phenol) as a medium and binder for the metallic powder. This process was developed by Zundel at Moscow. Another process for the metallisation of fabrics is described by Lang [1] as follows. " A solution of India rubber in naphtha or other solvent is prepared and a metallic powder added and the whole mixed until a homogeneous liquid is obtained. The fabric is wetted in the liquid and dried. A trace of amyl acetate may be added to the liquid to give a better luster. An example is given in which 16 parts by weight of naphtha, 2 of India rubber, 2 of metallic powder and 0.5 of amyl acetate are used."

Metallic threads are used for quite a large number of fabrics, such as passementerie work, trimmings, brocades, decorative embroidery, church vestments, fancy costumes, tapestries, fancy vestings, etc.

21. Slag Wool.—Slag wool is prepared by blowing steam through molten slag; it can scarcely be called a textile fiber, but it is used in some degree as a packing material. It (also known as *mineral wool* and in England as *silicate cotton*) is an interesting by-product from the blast furnace. The process of manufacture consists in subjecting a small stream of molten slag to a strong blast of steam or compressed air. This has the effect of breaking it up into minute spherules, and each small bead particle as it is blown away carries behind it a thread of finely drawn-out

[1] *Fr. Pat.* 509,492.

slag, thus forming extremely delicate filaments resembling fine glass threads. These fine threads are often 2 to 3 ft. in length, but readily break up into smaller ones and in bulk look like a mass of cotton of a dingy white color. The fiber is classified according to fineness into two grades (1) ordinary, including all fiber weighing over 14 lbs. and less than 24 lbs. per cubic foot; and (2) extraordinary, including fiber weighing less than 14 lbs. per cubic foot. Slag wool has the property of great lightness combined with that of being absolutely fireproof; it is also a very good non-conductor of heat and sound. Slag wool is not spun into yarns or made into fabrics after the manner of asbestos, but is used as a felt consisting of fine, interlocking mineral fibers enclosing a mass of minute air cells which gives it the property of being such a good non-conductor of heat. Coleman, in this connection, gives the following table showing the relative heat-conducting powers of various materials:

Slag wool	100
Hair felt	117
Cotton felt	122
Sheep's wool	136
Air space	280

The fibers of slag wool are very brittle and the fine, sharp points readily cut into the skin. In factories making this material care should be taken to properly protect the workmen from getting the fine needlelike particles into the eyes and lungs. Another disadvantage of slag wool is that it usually contains sulfur, so when it is in contact with water or moisture, sulfuric acid is gradually formed, which may result in the corrosion of metallic surfaces. This defect may be obviated by the selection of slag free from sulfur for the preparation of the fiber.

22. Artificial Silks.—Artificial silks are made from cellulose derivatives by forcing solutions of these through fine capillary tubes, coagulating the resulting threads, and subsequently subjecting them to various processes of chemical treatment. As these belong more strictly to the class of true textile fibers, they will be given a more extensive consideration, in a further section, as being derivatives of cellulose.

23. Other Forms of Artificial Fibers.—During the World War a number of different artificial fibers were developed in Germany. One of these is interestingly described as follows: By grinding with water in a ball-mill or other suitable means, wool, hairs, horn, leather, and their wastes, such as dust, clippings, and short fibers which are too small of themselves to permit of their use in the ordinary way, can be very finely divided. While finely ground substances of this kind cannot be used for the manufacture of paper except under great difficulties, as there is no cohesion between the individual particles, nor can they be used for artificial silk manufacture,

it has been found that it is possible to produce from these substances fibers which can be spun. This is done by making films by forming a solution of the wastes in question with suitable substances such as gelatine, size, acetyl cellulose, or other viscous solutions of cellulose or cellulose compounds. The films are cut up into fine fibers which are suitable for spinning, or the films are cut into strips, or produced in strip form so that these can be spun in the manner adopted for paper yarns. By this method new fibers and spun yarns can be produced which—especially when gelatine or size is the binding medium—possess the properties of wool to a very high degree. In order to render gelatine or size (glue) insoluble, the necessary quantity of a chrome compound (bichromate or chrome alum) is added to the mixture. Materials for producing pliability can be added, such as glycerol or certain ester compounds, such as triphenyl phosphates. Oils and fats can also be added, especially those that do not dry and that form emulsions easily.

The film may be experimentally produced as follows:

Upon a 13×18 cm. glass plate covered with a thin layer of wax the following mixture is worked up, evenly distributed and then dried at a moderate temperature:

12 cc. of a 5 percent solution of gelatine.
3 cc. of a 10 percent paste of the finest ground wool.
0.5 cc. of glycerol.
1.2 cc. of a 5 percent chrome alum solution.

When this mixture is dry it forms a non-curling elastic film about 0.07 mm. thick, which can easily be removed from the wax coating. Thin or thick films can be obtained according to the quantity of the mixture. Even films of 0.03 mm. have been found to be of use. These films can be cut into extremely fine fibers by employing suitable cutting devices; and then they may be spun alone or mixed with other fibers. Instead of using the binding medium mentioned above, the finely ground wastes can be mixed with paper pulp, paper being obtained from the mixture; this is then parchmented in the ordinary manner with a sulfuric acid of 1.7 sp. gr. or with a warm solution of zinc chloride of 1.9 sp. gr., and then washed. In this way parchment papers can be obtained which have a wool content of 50 percent and more, and which by suitable treatment and additions can be made pliable and waterproof.

24. Fiber Microscopy.—The examination of textile fibers under the microscope is a very important and essential aid to a study of these materials. Microscopy in any case requires the acquisition of a certain amount of delicate technique and skill on the part of the observer, and this is particularly true in the case of fiber microscopy. A knowledge of the proper methods of preparing specimens for examination, of mount-

ing them and of the proper selection of lenses, is of importance. The markings and the structure of the various fibers can only be brought out in their characteristic appearance by the employment of careful skill and this can only be developed by considerable practice and a close knowledge of the possibilities of the microscope. The preparation of micrographs and of microphotographs so as to bring out the characteristic features of the specimens under examination also reqaires considerable study and experience, and in the latter case, an additional knowledge of the possibilities and limitations of photography.

It is not possible at this point to take up in detail the subjects of microscopy and its related branches, although it will be well to present to the reader some of the leading features relating particularly to the field of fiber microscopy, with a brief consideration of the apparatus required and the methods of preparing and examining the specimens.

In the first place, a fairly good microscope is required, with a good system of the best lenses. While excessive magnification is not necessary, the lens system should be selected so as to obtain a clear flat achromatic field which will admit of a good focus over a considerable area. It must be borne in mind that fibers are more or less rounded filaments and are not thin, flat specimens like the delicate cross-sections of objects that are mostly the subjects used in microscopy. On this account it is necessary to have a good depth of focus in order to prevent undue distortion of the fiber which might lead the unskilled observer to a very erroneous idea of the markings on the subject. A very complete range of magnifications may be obtained with the use of No. 5 and No. 10 eye-pieces in combination with the following objectives: $\frac{2}{3}$ in. (16 mm.), $\frac{1}{3}$ in. (4 mm.) and $\frac{1}{12}$ in. (1.9 mm.). The last-named objective requires an oil immersion system and is only used for very high powers and delicate work which would be somewhat out of the ordinary.

The following table gives the various magnifications available with the objectives and eye-pieces mentioned:

Objective.	Eye-pieces.	
	No. 5.	No. 10
$\frac{2}{3}$ in. or 16 mm.	50	100
$\frac{1}{6}$ in. or 4 mm.	215	430
$\frac{1}{12}$ in. or 1.9 mm.	475	950

It is well to have a microscope set fitted with a revolving nose-piece for two or three objectives so that the fiber may first be picked up with a low power and then observed finally with a suitable high power. An adjustable stage is also convenient for moving the specimen mount and for locating positions. The use of a sub-stage diaphragm and condenser for obtaining proper conditions of illumination is also quite important in

good fiber microscopy, as very frequently important points of observation can only be brought out by adjusting the illumination of the specimen. An achromatic sub-stage condenser and an iris diaphragm are usually supplied with the better sets of microscopes. The accompanying illustration (Fig. 4) shows a popular form of microscope with the necessary accessories suitable for fiber investigations.

Fiber specimens may be mounted in various ways; for temporary mounts and rapid observation an ordinary water mount may be used. The fibers should be well separated so that as few as possible cross over one another, and if necessary cut in short lengths to come within the area of the cover glass. These fibers are then laid neatly on the glass slide, a drop of water is touched to them by means of a dropper or a glass rod, and then the cover glass is laid over them and gently pressed down so as to flatten out the specimen. In making observations under high power it is especially necessary that the fibers be as single as possible, for if several are piled up across one another the focus becomes distorted, and unless the observer is skilled in these observations he may mistake shadows for important markings. The water mount is only of a temporary character, as the cover glass is just loosely held in place and the water quickly evaporates. Where a permanent mount is desired, or where it is necessary to have a very flat field for high power observation, the specimen may be mounted in Canada Balsam, which dries like a varnish and cements the cover glass firmly in place. This kind of mounting, however,

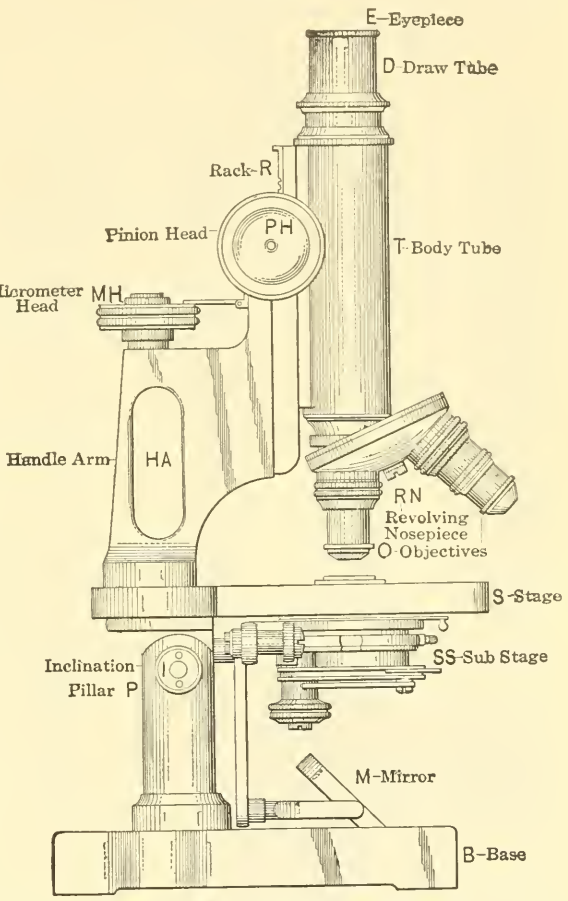


Fig. 4 —Diagram of Microscope Showing Essential Parts.

generally makes the fiber very transparent and may obliterate many of the characteristic markings both on the surface and in the interior. To bring out these markings it may be necessary to first treat the specimen with certain reagents, such as various stains used especially in microscopy, silver nitrate and other chemicals. Glycerol, cedar oil and some other mediums are also used at times for mounting fiber specimens. The effect of mounting in different media is shown in Fig. 5, which shows a fiber of Egyptian cotton mounted as follows: (1) plain air mount; (2)

Fig. 5.—Cotton Fibers Mounted in: (*A*) Air, (*B*) Water, (*C*) Glycerol, (*D*) Cedar oil, (*E*) Anisol, (*F*) Mono-bromnaphthalene. (Herzog.)

in water; (3) in glycerol; (4) in cedar oil; (5) in anisol; (6) in monobromnaphthalene.

It is often desirable to draw the appearance of the fiber under the microscope so as to preserve a permanent record. For this purpose several forms of projection attachments to the microscope are available, such as the Abbe ocular shown in Fig. 6. Another form of apparatus is shown in Fig. 7. Both of these instruments project the image down on a piece of paper on which the outlines are drawn. A more satisfactory though more complicated and costly equipment for projection drawing is

shown in Fig. 8. In making these drawings or micrographs, however, a certain amount of skill and talent at drawing is required, but this can be developed with experience and painstaking care. It is usually necessary

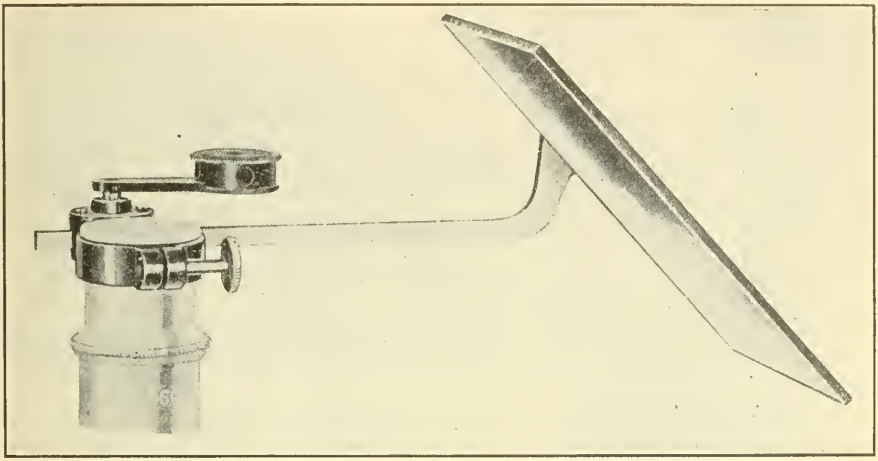


Fig. 6.—Abbe Projection Apparatus for Drawing from Microscope. (Bausch & Lomb.)

for the observer to possess good draughting abilities, however, to obtain satisfactory results.

A polariscopic attachment is also of considerable use in the observation of fibers under the microscope, as this brings out the interior structure of the fiber in a remarkable manner; it is especially useful in obtaining good micro-photographs where structural qualities are desired (see Fig. 9).

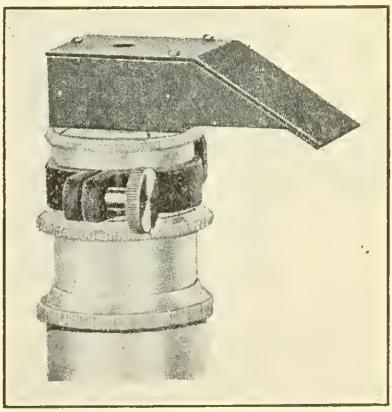


Fig. 7.—Attachment used for Projection Drawing. (Bausch & Lomb.)

To obtain permanent records of fiber microscopy so that the appearance of the specimen may be studied and observed at leisure, it is necessary to use a photographic attachment whereby a real photograph may be taken of the magnified object. A very useful form of such an apparatus is shown in Fig. 10, and it is well to use a special electric lamp for illumination so as to obtain a clear image and permit of a negative being taken in a reasonably short time.

Cross-sections of fibers for microscopic mounts may be made by taking a small strand of fibers arranged in as parallel a fashion as possible and imbedding them in a special preparation of melted wax, allowing the speci-

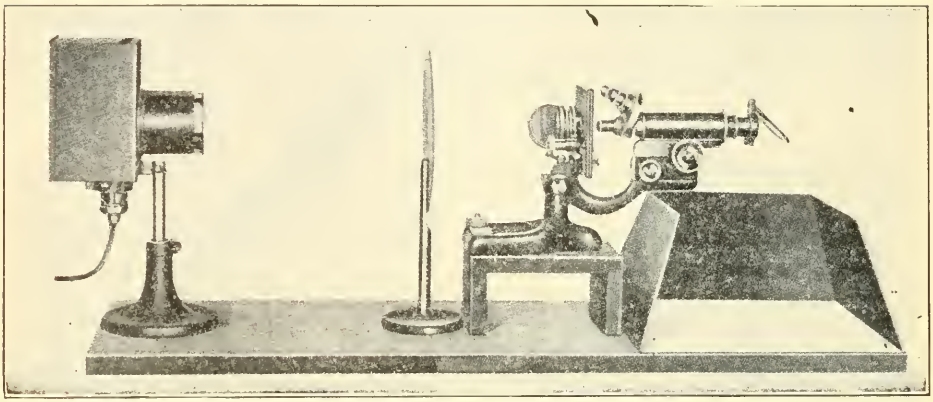


FIG. 8.—Micro-Projection and Drawing Equipment. (Bausch & Lomb.)

men to cool and then cutting thin cross-sections on a microtome (see Fig. 11). Further details as to such preparations will be considered under the microscopic examination of the various fibers.

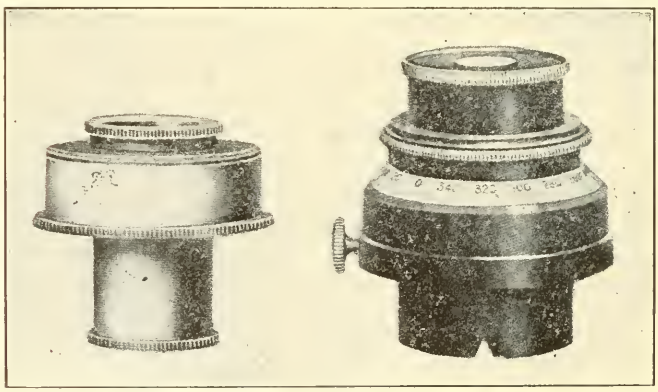


FIG. 9.—Polariscopic Attachment for Microscope; (*A*) Polariser, (*B*) Analyser (Bausch & Lomb.)

A very necessary adjunct for the measurement of fiber diameters is the micrometer ocular. This not only serves for the simple observation of fibers, but also for their measurement. For this purpose, a glass plate on which a small scale is etched is placed between the ocular and the condensing lens. Sometimes the scale is photographed on the plate. It is

usually a centimeter divided into 100 parts, or a half-centimeter divided into 50 parts. If a fiber of a certain thickness is examined several times successively with this micrometric ocular, but with different objectives, it will be noticed that the divisions on the scale always remain the same size, but the fiber will appear larger or smaller depending on the strength

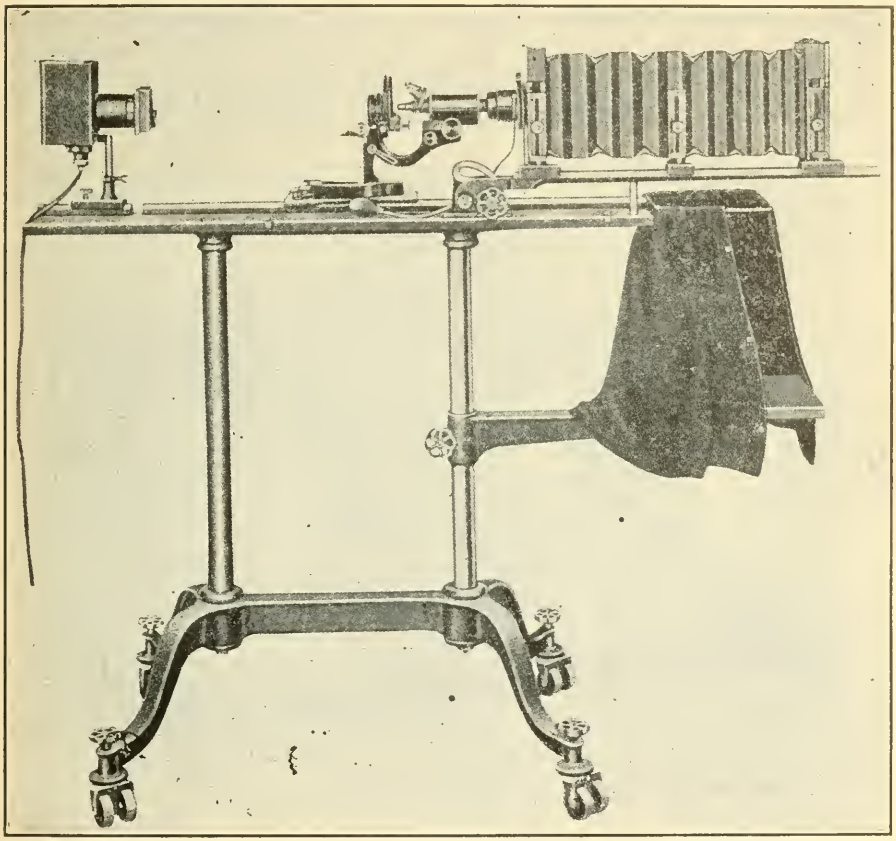


FIG. 10.—Installation for Preparing Photomicrographs of Fibers.
(Bausch & Lomb.)

of the objective. From this it is evident that a division on the micrometric scale will have different values, depending upon the lens system with which it is used. The ocular micrometer is therefore standardised for each system on an objective micrometer, which is a very finely divided scale ruled on glass.

25. Statistical.—The industries related to the preparation and utilisation of textile fibers rank among the most important in the industrial life

of all nations. In the United States the cotton, wool and silk industries are of vast extent, not only with respect to the manufacturing part, but also to the merchandising and distribution of the products. In England the cotton and woolen industries form the chief sources of the wealth of the nation. In our own country the cotton industry ranks easily first with a capital investment of nearly two billions of dollars and with a yearly value of products exceeding this sum. Second in importance come the industries related to the wool fiber, including woolen and worsted goods. A very close third is the silk industry, with a capitalisation of over half a billion dollars, and with a present output of about three-fourths of a

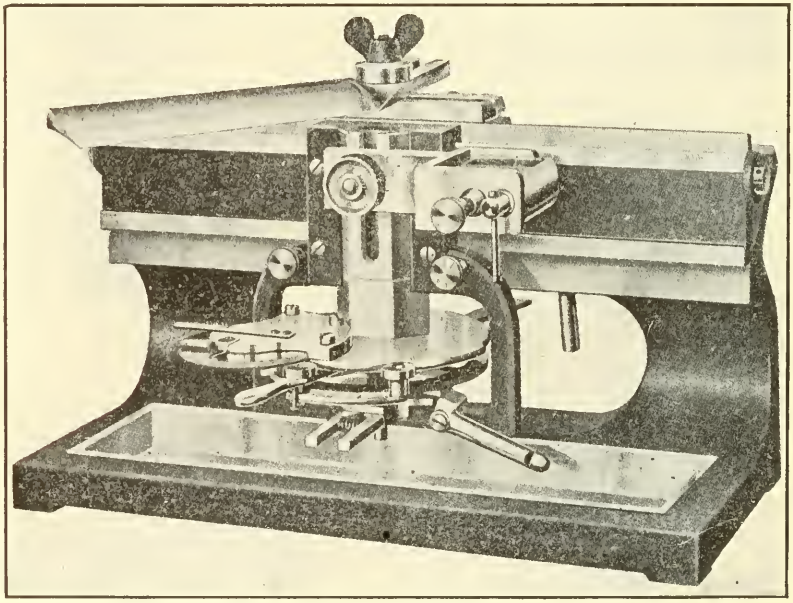


Fig 11.—Microtome for Cutting Fiber Sections. (Bausch & Lomb.)

billion dollars in value of manufactured goods. To the fiber industries proper must also be added that relating to the manufacture of artificial silk, though this is considered more specifically under the term of chemical industry. The size of this latter industry is growing with great rapidity in this country, and will soon rank with the silk industry itself in importance and economic value.

The following table shows the extent of the fiber industries in the United States for the year 1919 (*Census Reports*):

Industry.	No. of Establishments.	Capital Invested.	Salary and Wages Paid.	Cost of Materials Used.	Value of Products.	Salaried Employees.	Wage Earners.	Horsepower Used.
Cotton	1288	$1,853,099,816	$392,839,415	$1,277,785,597	$2,125,272,193	14,218	430,966	1,840,201
Woolen	560	273,973,670	79,736,922	212,189,028	364,896,590	3,805	62,957	172,947
Worsted	292	557,721,078	119,353,515	438,007,587	700,537,482	5,415	103,830	295,533
Silk goods	1369	532,732,163	134,597,292	388,469,022	688,459,523	8,982	126,782	176,825
Linen goods	10	7,527,596	1,964,967	4,190,187	6,998,046	180	1,890	6,069
Dyeing and finishing	628	229,948,486	73,441,533	174,742,815	323,967,683	6,240	55,985	160,430
Felt goods	49	35,024,373	6,970,832	22,780,775	39,229,540	690	5,236	16,411
Feathers and plumes	216	6,514,809	4,429,729	6,694,596	15,377,953	481	3,504	273
Fur goods	1815	80,700,925	32,142,358	105,596,605	173,137,739	3,668	13,639	5,327
Hair cloth	18	2,999,150	569,059	2,259,142	3,315,113	67	425	1,153
Awnings, tents, sails	895	26,727,621	8,860,670	26,961,140	45,690,390	1,514	6,028	4,589
Brushes	379	27,208,200	10,761,795	19,598,133	39,005,607	1,643	7,968	7,384
Carpets and rugs	75	119,196,461	28,965,905	67,118,039	123,253,828	1,268	22,933	38,170
Cordage and twine	120	100,248,987	18,715,562	89,705,282	133,366,476	1,581	17,622	66,643
Cotton lace	44	32,260,216	8,110,998	13,075,994	29,396,853	698	6,490	9,078
Cotton small wares	164	29,559,474	9,537,260	24,039,951	40,896,835	759	9,396	14,263
Hats, fur felt	176	58,127,770	24,274,203	40,158,019	82,745,308	1,660	18,510	20,389
Hats, woolen felt	40	3,831,376	1,746,028	3,699,822	6,739,652	157	1,448	2,696
Jute goods	26	41,335,845	7,550,301	17,708,834	34,442,698	436	7,138	32,135
Knitgoods	2050	516,457,991	157,526,402	427,095,560	713,139,689	12,613	172,572	151,601
Matting	12	7,190,675	1,040,251	2,102,580	4,860,855	93	1,073	1,670
Nets and seines	19	4,155,531	770,487	3,648,206	5,114,414	79	859	959
Elastic woven goods	196	39,676,879	12,861,203	36,369,218	60,774,652	1,430	10,857	9,028
Wool pulling	24	8,853,437	1,192,996	12,809,592	17,361,231	111	705	2,162
Wool scouring	33	10,049,960	3,623,627	7,228,350	13,679,584	221	2,177	9,790
Wool shoddy	78	16,990,722	3,670,392	16,076,315	23,254,398	326	2,566	16,694

CHAPTER II

ASBESTOS AS A TEXTILE FIBER

1. Occurrence.—The principal and, strictly speaking, the only mineral fiber is asbestos, which occurs in nature as a mineral of that name. The word is derived from the Greek and was used by Dioscorides and other Greek writers as a term for quicklime, but Pliny fixed its meaning in its modern sense. It is a fibrous silicate of magnesium and calcium, though often containing iron and aluminium in its composition, especially in the dark-colored varieties. The general term "asbestos" includes the fibrous varieties of both serpentine and hornblende. Serpentine is a compound silicate of magnesium and calcium, always containing iron, and generally also some manganese. Hornblende (also known as amphibole) is very similar in composition, but often contains aluminium.

The composition of asbestos from different parts of the world differs considerably, as the following analyses indicate:

	Cyprus, Percent.	Italy, Percent.	Thetford, Canada, Percent.	Templite, Percent.
Silica (SiO_2)	40.50	40.30	40.57	40.52
Alumina (Al_2O_3)	1.09	2.27	0.90	2.10
Iron oxide (Fe_2O_3)	4.87	0.87	2.81	1.97
Magnesia (MgO)	39.02	43.37	41.50	42.05
Water (H_2O)	13.47	13.72	13.55	13.46

Canadian asbestos is considered best, and provides about 75 percent of the world's consumption of this material.

The asbestos mineral, though in the form of a hard rock, can be easily separated into slender white fibers (Figs. 12, 13 and 14), sometimes inclining toward a greenish color. The asbestos mineral has a density of 2.5 to 2.8, and a hardness of 3 to 5. The individual fibers of asbestos are so fine as to approach the limits of microscopic measurement, which is $\frac{1}{2}$ micron = 0.0005 mm.[1] There is no reason for supposing that these

[1] The micron is a unit of measurement much used in microscopic work; it is equivalent to one-thousandth millimeter. The symbol *mu* or Greek letter μ is often used for the term micron.

extremely fine fibers of asbestos may not be capable of still further subdivision; in fact, there appears to be scarcely any limit to this possible subdivision (see Fig. 15). The asbestos fiber, however, is evidently a crystal and is angular and not round; presumably the cross-section is square, though this has yet to be definitely established. Owing to the unlimited splitting of the fiber it is difficult under the microscope to determine its proper form.

Fig. 12.—Chrysotile Asbestos from Canada.

2. Varieties of Asbestos.—The fibers of some varieties are curly, and afford the best material for spinning. Italy was perhaps the first of modern nations to use asbestos as a textile material. Experiments in this line were encouraged in Lombardy by Napoleon I, but it was not until about 1866 that any practical commercial results were obtained, and both asbestos cloth and paper were made. No serious attempt was made to mine Canadian asbestos until 1878, when the valuable deposits at Thetford and Black Lake in Quebec were exploited. The finest quality of long "floss" asbestos fiber is still obtained from the Italian mineral. There is a piece of asbestos cloth in the Vatican Museum said to date from Roman times; it is of rather coarse construction and was evidently made by spinning the asbestos with vegetable fiber (linen). Asbestos cloth was noted by Marco Polo (thirteenth century) in his travels in Tartary and China. The lamp wicks mentioned by Plutarch as used in the "perpetual" lamps of the Vestal Virgins were made of asbestos fiber. Pausanias refers to such wicks

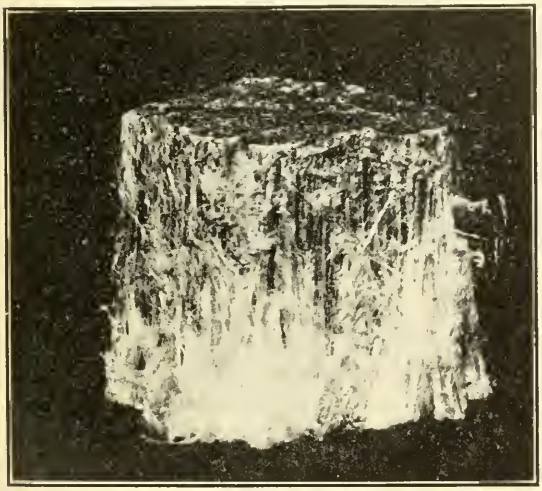


Fig. 13.—Piece of Asbestos Rock as Mineral. (Johns-Manville Co.)

as made from "Carpasian" linen, evidently meaning the mineral fiber obtained from Carpasius in Cyprus.

Asbestos fiber is known in Germany as "steinflachs" (stone-flax), in Italy as "amiantho," and the French Canadian calls it "pierre à coton" (cotton-stone).

The Italian asbestos (see Fig. 16) is mineralogically distinct, both in form and appearance, from the Canadian chrysotile. Notwithstanding their physical differences, however, their chemical composition is very

FIG. 14.—Asbestos Rock Broken Apart Showing Fine Fibrous Structure. (Johns-Manville Co.)

similar, and when reduced to commercial fiber, they are practically identical.

The blue asbestos of South Africa is the mineral crocidolite. The fiber is easily separated by the fingers; the sp. gr. is 3.20 to 3.30; the luster is very silky and the color is a dull lavender blue, due to the presence of ferrous oxide. The fibers are quite elastic and often several inches long. Its chemical composition is quite different from either chrysotile or Italian hornblende, being as follows:

	Percent.
Silica	49.6
Iron sesquioxide	22.0
Iron protoxide	19.8
Soda	8.6

As compared with Canadian asbestos it has a high tensile strength but poor heat-resisting qualities, and this greatly limits its commercial value.

There is considerable confusion and misconception as to the proper mineralogical character of asbestos, and this has probably arisen from the use of the name in a somewhat generic sense. Dana, in his *Mineralogy*, says that asbestos is a finely fibrous form of hornblende, but much that is so called is fibrous serpentine. This statement seems to have divided most writers on the subject into two camps, the one calling the mineral a variety of hornblende, while the other claims it to be derived from serpentine. The asbestos of commerce is really a hydrated silicate of magnesium, of the same composition as ordinary serpentine rock; in other words, it is a fibrous serpentine.

Fig. 15.—Asbestos Fiber. (×5.) (Micrograph by author.)

In a mineralogical sense the term asbestos is really a generic one, and the mineral occurs in a variety of species, some of which are much more valuable than others for fiber purposes. In some the fibers are slender and easily separable, and of a white or greenish color. A variety known as *amianthus* gives fibers of a fine silky quality. *Ligniform asbestos* is a hard compact variety, resembling petrified wood in appearance, and brownish to yellowish in color; a wool-like variety found near Vesuvius is known as *breislakite*. *Mountain flax*, *mountain cork*, and *mountain leather* are all varieties of asbestos, the last consisting of a naturally felted mass of asbestos fibers.

The chief commercial variety of asbestos is a form of serpentine and it differs from the hornblende variety in that it contains about 14 percent of water in its composition. *Picrolite* is another fibrous variety of serpentine and closely resembles coarse asbestos (see Fig. 17). It occurs in nearly all Canadian asbestos mines and is known as *bastard asbestos*. The fiber is sometimes very long (over a foot) but is harsh and brittle and unsuited for commercial purposes.

Chrysotile asbestos furnishes the most valuable commercial fiber as it combines the best length and fineness of fiber with infusibility, tensile strength and flexibility. These factors must always be taken into con-

sideration when judging the suitability of any mineral fiber, and though there are several other minerals of a fibrous silky character, their fibers

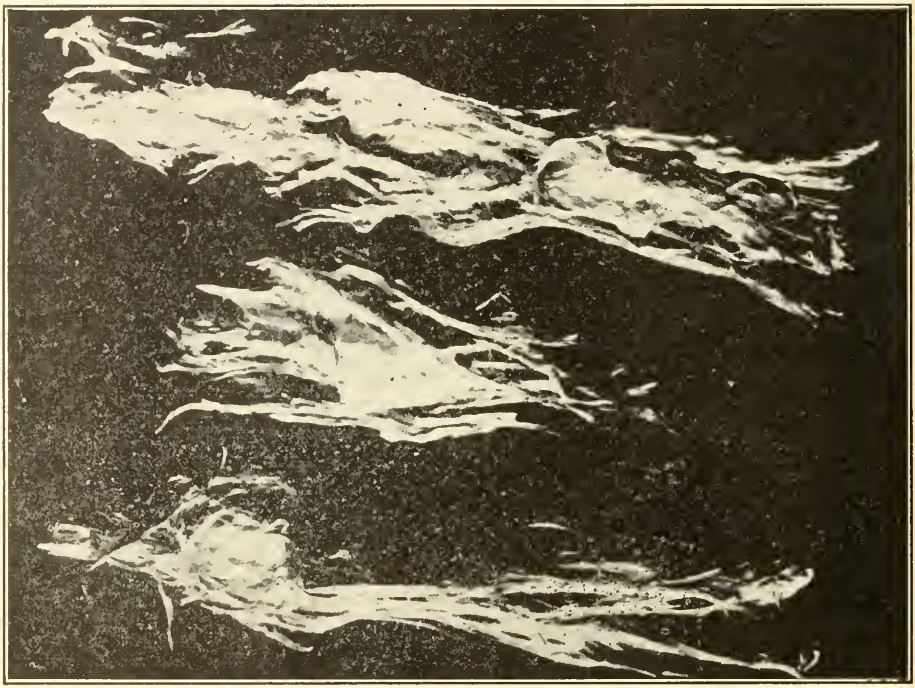


FIG. 16.—Italian Asbestos from Hornblende.

usually fail to compare favorably with chrysotile asbestos. The heat-resisting qualities of both amphibole asbestos and chrysotile asbestos are

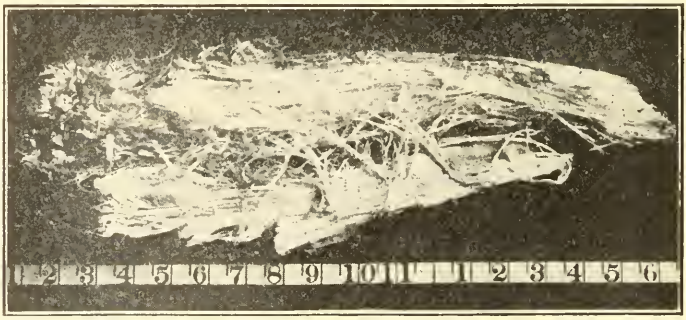


FIG. 17.—Picrolite or Bastard Asbestos of Long Fiber.

good, but where strength of fiber and spinning quality are desired, the chrysotile variety is much superior.

The difference in the chemical composition of chrysotile and amphibole asbestos is given in the following typical analyses:

	Chrysotile, Canadian, Percent.	Amphibole, Percent.
Silica (SiO_2)	41.90	61.82
Magnesia (MgO)	42.52	23.98
Alumina (Al_2O_3)	0.89	1.12
Iron oxide (Fe_2O_3)	0.69	6.55
Lime (CaO)	.....	1.63
Water (H_2O)	14.05	5.45

It appears that the greater the amount of water in an asbestos, the better and finer is the quality of its fiber. With a small percentage of water the fiber becomes brittle and will not spin. The softness of the fiber is proportional to the water content; a very silky asbestos may contain 15 percent of water, whereas that containing 11 percent or less is brittle

FIG. 18.—Crushed Asbestos Previous to Carding and Spinning. (Johns-Manville Co.)

and harsh. If a soft-fibered variety of asbestos is subjected to a high heat, a portion of its combined water will be driven off, and the fiber will then lose its flexibility and spinning qualities.

The fibers of chrysotile are to be distinguished from those of hornblende by the fact that the fiber-bundles of the former are partly decomposed by hydrochloric acid and completely so by sulfuric acid, whereas

hornblende (or amphibole) asbestos is not acted upon by either acid. Chrysotile asbestos is also the denser, and is of a white, straw-yellow to brown, or bluish color, depending on the content of iron oxide (which is sometimes as much as 30 percent). The amphibole asbestos is of less density, contains only about 5 percent of chemically combined water, and on account of its very brittle fiber is not capable of being spun; the color is gray-white to pink. It occurs in commerce chiefly in the powdered form, and is used in the manufacture of heat-insulating materials. Chrysotile can only withstand a temperature of 300° to 500° C. without loss in strength, but amphibole may be heated to 1000° to 1200° C. without essential alteration. Canadian asbestos is the most valuable as a source for textile purposes, as it yields a curly fiber easily spun into threads.

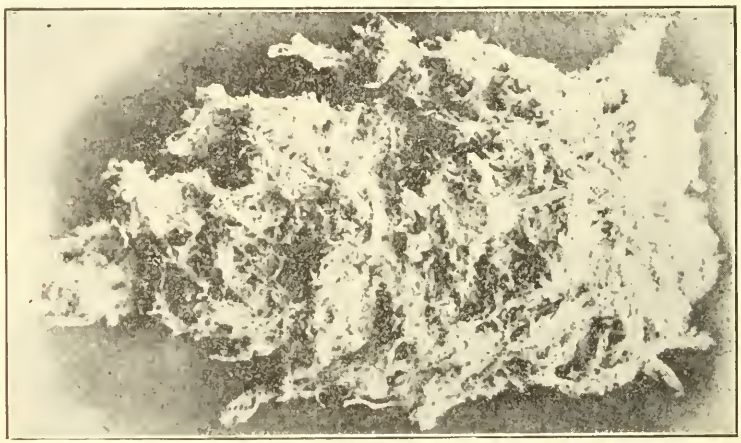


Fig. 19.—Fiberised Asbestos ready for Market.

The length of the fiber varies with the thickness of the rock, and this runs from a fraction of an inch up to about 4½ inches (see Figs. 18 and 19). Some Italian varieties are said to reach the exceptional length of 5 to 6 ft., but are harsh and brittle. The serpentine asbestos usually occurs in rather narrow veins and yields fibers of but 2 to 3 ins. in length.

3. Grading of Asbestos.—Asbestos fiber is usually graded into three qualities according to the length of staple; Grade No. 1 is valuable for spinning; while No. 2 and No. 3 are used for making mill-board or insulating materials. The different grades of fiber are separated by shaker machines and air blowers.

Asbestos fiber is divided into four distinct groups: (*a*) *Cross fiber*, which has the greatest commercial importance, occurs in distinct veins extending from wall to wall of the serpentine rock. The fibers vary in length from a fraction of an inch to about 2 ins. (*b*) *Slip fiber* runs parallel

with the fracture planes produced by the crushing and shearing of the rocks. This fiber is not as well adapted as the foregoing to spinning purposes. (*c*) *Mass fiber*, as the name suggests, does not occur in fissures, but in masses. The conditions which produce mass fiber are essentially different from those which produce cross and slip fibers, and when mass fiber is found it is rarely that the other forms occur in the same rock. (*d*) *Shear fiber* is made up of cross fiber that has been sheared by a subsequent movement of the rocks. These fibers are found lying parallel with the fracture planes, but evidently altered in their direction after formation. The shear fiber is equal in strength, fineness and flexibility to the best cross fiber, and may sometimes be found as long as 6 ins.

There can be little doubt that there is a definite relation between the softness of the asbestos fiber and the quantity of water of constitution it contains; 14.38 percent water has been found in very silky fiber, while a harsh, brittle sample gave only 11.7 percent. This will explain the extreme brittleness of the amphibole fiber, some samples of which contain only 5.45 percent water. The effect of high temperatures on very soft fiber also demonstrates this fact. When part of the combined water has been driven off by excessive heat, the fiber loses its flexibility and becomes harsh and brittle; and the variations in strength and silkiness in various deposits of the mineral are best explained by assuming that the water content was originally nearly the same in all cases, and that the movement of associated rocks or the injection of molten rock has furnished sufficient heat to drive off part of the water.

The world's consumption of asbestos (1912) was about 100,000 tons, of which about 75,000 tons came from Canada. In 1918 the production of Canadian asbestos amounted to 143,743 tons, and in 1920 to 174,521 tons. Asbestos produced in the United States in 1918 amounted to only 800 tons. About 50,000 tons of short-fiber asbestos mill-board and paper are used each year in building construction.

It was formerly claimed that Canadian asbestos was inferior to that from Italy, and that it was also a different species of mineral. This, however, has long been proved to be erroneous, and the identity of the two may be seen by reference to their chemical analysis. Up to about 1875, nearly all the commercial asbestos came from Italy, but the cost of producing it, due to the local difficulties in mining, made it too costly for general use; a considerable quantity, however, still comes on the market from this source. The Italian asbestos is mostly amphibole and is not as valuable as the chrysotile variety. The Canadian supplies are derived from quarries in the neighborhood of Quebec. The deposits occur in a narrow zone of serpentine rocks extending from about 40 miles south of Quebec to a point within the United States. Asbestos also occurs in many other parts of the world, though not of the proper quality

to make it commercially useful. It is found in the vicinity of Port Bag, Newfoundland, but the locality so far is very inaccessible. It also occurs in various parts of the United States, in Russia, Siberia, Finland, Cyprus, Queensland, South Australia, New South Wales, New Zealand, Rhodesia and China. A lavender-blue variety which is obtained from South Africa is said to possess great strength and may in time compete with the Canadian variety. A rather recent important field of asbestos is in western Spitzbergen. It is being quite extensively operated and yields a highly fibrous, pure amphibole asbestos.

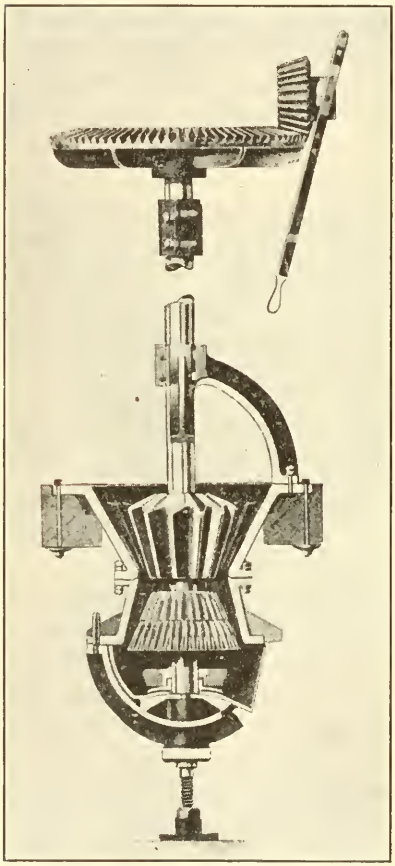


FIG. 20.—Rotary Crusher for Asbestos. (Butterworth & Lowe.)

4. Asbestos Yarns and Fabrics.—In general the fibers of asbestos are straight and glassy in structure and are difficult to spin into a coherent thread. In order to enhance its spinning qualities it is mixed with a little cotton or linen, the latter fiber being subsequently destroyed by heating the woven fabric to incandescence. By improved methods of handling, however, it is now possible to spin asbestos directly without admixture with cotton. The asbestos rock is first run through a crusher where it is fiberised (see Figs. 20 and 21). By the use of special machinery it is then separated into long and short fiber; the latter is utilised for the manufacture of mill-board and asbestos paper, while the former is further processed by carding and spinning to make a twisted yarn.

The numbering of asbestos yarn is based on the number of lengths of 100 yds. that weigh 1 lb.; thus No. 2 yarn indicates that 200 yards weigh 1 lb. As single yarns lack uniformity, all asbestos yarns come into the market as ply yarns, up to 6 or 8 threads. Summers states that asbestos yarn can be spun to weigh less than an ounce to a length of 100 yds. and fine asbestos cloth can be made weighing only a few ounces to the square yard. Such fabrics, however, are curiosities rather than commercial articles. The asbestos yarns and fabrics appearing on the market would

be classed as crude and coarse in quality as compared with ordinary textile fabrics. For special purposes a fine brass wire is sometimes twisted with the yarn.

At the present time quite a variety of fabrics are manufactured from asbestos fiber, and the high quality of many articles appearing on the market shows that the art of manipulating this substance has reached a high degree of perfection. On account of its incombustible nature, and as it is a very poor conductor of heat, it is made into fabrics in which these qualities are especially desired. Thus it is frequently manufactured into gloves and aprons, packing for steam-cylinders, theatrical curtains and scenery, lamp wicks, etc. The use of asbestos in lamp wicks was

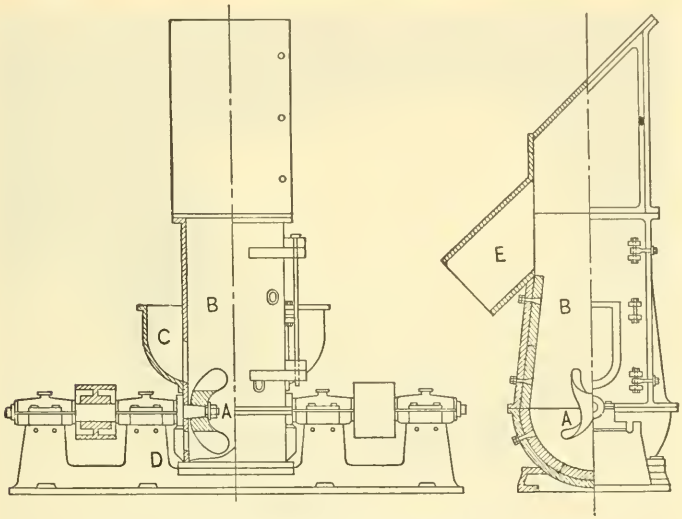


Fig. 21.—Cyclone Fiberiser for Asbestos. (Laurie.)

known to the ancients, who employed it for the wicks of the perpetual lamps in their temples, and it was also used as a shroud for the cremation of the kings. It is from this fact, indeed, that it received its name, the word "asbestos" meaning "unconsumed." In later times it was known as "salamander wool," being known by this term in China, where it was used as early as 1600 for the weaving of napkins. It was also said to be employed for napkins on account of being readily cleansed, it only being necessary to heat the fabric in a flame to make it clean again. This statement, however, is without doubt mythical, together with a similar one regarding the asbestos table cloth of Charlemagne. In this connection it may be noted that there is considerable misconception as to the effect of high temperature on asbestos. It is true that asbestos is infusible except at very high temperatures, and also that it is perfectly non-combustible and non-inflammable; nevertheless, it requires only a moderate

degree of heat (dull redness, for example, in a crucible), to entirely destroy the flexibility of the fiber and to render it so brittle that it may be easily crumbled to a powder. This is due to the fact that the heat drives off the water of hydration from the asbestos, and in this state the fibrous structure easily breaks down.

At the present time one of the principal uses of asbestos yarns is in the manufacture of cloth for the lining of brake bands for automobiles. Asbestos cloth is also used quite extensively in a number of chemical operations, especially for the filtering of acids or other corrosive liquids.

In some cases asbestos is spun directly around a copper wire for purposes of insulation. Asbestos, in general, is not dyed, and does not undergo

Fig. 22.—Spool of Asbestos Yarn. (Johns-Manville Co.)

any chemical processes or modes of treatment. When it is desirable to dye it the various substantive dyes may be used with good effect, or the color may be applied by mordanting with albumen.

Owing to the extending use of asbestos yarns they are now made in quite a variety of sizes and composition. The commercial yarns in common use range from 400 yds. to 4000 yds. to the pound single-ply, and may consist of pure asbestos fiber or varying mixtures with cotton, according to specification. A single yarn running 1000 yds. to the pound will about compare in size to a 4's cotton yarn. Most asbestos fabrics are made from 2-ply yarn having a small percentage of cotton to give them additional strength; this is especially true of cloth for theater curtains and the like. For the manufacture of automobile brake bands, yarns of pure asbestos twisted with wire are used.

Asbestos fabric is largely used for packing joints and glands in high-pressure steam engines, for which purpose the fabric is usually a combination of asbestos yarn and metallic wire. The use of asbestos cloth of this character is very extensive, and is becoming more and more essential in engineering practice. Asbestos cloth is also used as clothing for furnace men in the metallurgical industries, it being the only material for this purpose that is sufficiently flexible and fire-resistant and at the same time serves as a heat insulator. The fabric used for fireproof curtains for theaters is woven of asbestos and wire yarns. The manufacture of this cloth is now carried out on quite an extensive scale, as it is required by practically every theater in modern cities. Asbestos cloth is also used for wall linings in theaters and in the making of various forms of theatrical scenery. Asbestos fabric has also been used in the making of a form of artificial leather that closely resembles the natural product in appearance and characteristics, but is waterproof and fireproof. It is known in trade as "Dellerite" and "Bestorite." It is a combination of asbestos fiber and vulcanised rubber worked together under enormous pressure.

5. Properties of Asbestos Textiles.—Asbestos itself is not as good a non-conductor of heat as is generally supposed. Its non-conducting properties are more due to the fact that it is of a fibrous character and may be teased out into a fluffy mass, which like similar masses of wool or cotton enclose numerous air-spaces. Asbestos itself in the form of a compact board is a rather poor non-conductor; it is only when it is made into a mass possessing a fibro-cellular structure capable of occluding considerable air that it becomes a good non-conductor. Professor Ordway (*Eng. and Mining Journal*, 1890, p. 650) made a series of tests relating to the comparative values of different fibers as non-conductors of heat. His results are summed up as follows: A mass of the non-conducting material 1 in. thick was placed on a flat surface of iron kept heated to 310° F.; the amount of heat transmitted per hour through the non-conductor was measured in pounds of water heated 10° F., the unit of area being 1 sq. ft. of covering:

Substance.	Pounds of Water Heated at 10° F.	Solid Matter in 1 Sq. Ft. 1 In. Thick, Parts in 1000.	Air Occluded, Parts in 1000.
Loose wool	8.1	56	944
Goose feathers	9.6	50	950
Carded cotton	10.4	20	980
Hair felt	10.3	185	815
Fine asbestos	49.0	81	919
Air alone	48.0	0	1000

Strong sulfuric acid exerts a slight solvent action on asbestos. Treatment with sulfuric acid (80 percent) according to Heermann and Sommers, shows the following degrees of solubility with different varieties of asbestos:

	Solubility, Percent.
African Blue Asbestos	2.1
South African White Asbestos	12.3
Russian Ural Asbestos	2.4
Canadian Asbestos	8.3
German Asbestos (needle)	0.9

FIG. 23.—Typical Cloth Woven from Asbestos Yarn. (Johns-Manville Co.)

These figures represent the mean values of several determinations, and it is to be observed that not only do considerable differences appear with the different varieties, but there is also a considerable variation among different samples of the same variety of asbestos. It would seem that the degree of solubility is greater with increase in the fineness of the fibers of the sample.

Owing to this solubility of asbestos in strong sulfuric acid it is apparent that determinations of mixtures of asbestos and cotton fibers cannot be accurately made by destroying the cotton with this acid. The effect of the degree of fineness of the fibers on the amount dissolved by the sulfuric acid is shown by the following figures taken in connection with the preceding ones:

	Solubility, Percent.
African Blue Asbestos, coarse	1.6
South African White Asbestos, fine fibers	23.8
Russian Ural Asbestos, fine fibers	6.3
Canadian Asbestos, fine fibers	17.2
German Asbestos, powdered	3.7

It will be seen that very large variations occur, depending on the fineness of the fibers.

Even treatment with more dilute solutions of sulfuric acid show considerable effect on asbestos. The following figures show the amounts dissolved by treatment for forty-eight hours with a cold $\frac{1}{5}$-normal solution of

FIG. 24.—Gloves made from Asbestos Fabric. (Johns-Manville Co.)

sulfuric acid; the asbestos in all cases not being very finely divided into fibers:

	Solubility, Percent.
African Blue Asbestos	3.1
South African White Asbestos	39.6
Russian Ural Asbestos	13.6
Canadian Asbestos	19.4
German Asbestos	1.5

Treatment of asbestos with copper oxide-ammonia solution shows no loss in weight, according to Heermann and Sommers, and consequently this solution may be employed for determining the amount of cotton present in the sample of the mixed fibers. The material should be first washed with an alcohol-ether mixture to remove waxy substances, then teased out so as to give a loose fibrous mass and finally treated with a cold freshly prepared solution of copper oxide-ammonia with a high copper content.

CHAPTER III

WOOL: ITS ORIGIN AND CLASSIFICATION

1. The Sheep.—The woolly, hairlike covering of the sheep forms the most important and the most typical of the textile fibers which are obtained from the skin tissues of different animals. The hairy coverings of a large number of animals are employed to a greater or lesser extent as raw materials for the manufacture of different textile products, but those of the various species of sheep make up the great bulk of the fibers which possess any considerable technical importance.

Hairs, derived from whatever species of animals, have very much in common as to their general physical and chemical properties; they are also similar with respect to their physiological origin and growth. An animal hair consists of the *root* situated in a depression of the skin (hair follicle) and the *shaft*, or hair proper. In the typical hair three sharply defined tissues are present: the *epidermis*, or cuticular layer, the *cortex*, or fiber layer, and the *medulla*, or pith. Hairs are distinguished according to their length, stiffness, etc., as *bristles*, *bristle hairs*, *beard hairs*, and *wool*. The long, stiff, elastic hairs of the hog are typical bristles. Bristle hairs are short, straight, stiff hairs with a medulla, such as the body hairs of the horse. Beard hairs are the long, straight, or slightly wavy, regularly distributed hairs (generally with a medulla) which give the pelts of various animals their value. Human hair, and the hair from the manes and tails of horses, also belong to this class. Wool hairs are soft and flexible.

At what point an animal fiber ceases to be a hair and becomes wool is impossible to determine, because the one by imperceptible gradations merges into the other, so that a continuous series can be formed from the finest and softest merino to the rigid bristles of the wild boar. Thus the fine, soft wool of the Australian merino merges into the cross-bred of New Zealand; the cross-bred of New Zealand merges into the long English and luster wool, which in turn merges into alpaca and mohair materials with clearly marked but undeveloped scale structure. Again, such animals as the camel and the cashmere goat yield fibers which it would perhaps be difficult to classify rigidly as either wool or hair.[1]

The hairs of different animals vary much in the detail of their special characteristics, and also with regard to their adaptability for use in the

[1] See Barker, *Encyl. Brit.*

textile industry; and the wool of the sheep appears to exhibit in the highest degree those specific properties which make the most suitable textile fiber. These properties may be enumerated as being: (*a*) Sufficient length, strength, and elasticity, together with certain surface cohesion, to enable several fibers to be twisted or spun together so as to form a coherent and continuous thread or yarn; (*b*) the power of absorbing coloring matters from solution and becoming dyed thereby, and also the property of becoming decolorised or bleached when treated with suitable chemical agents; (*c*) in addition to these qualities, which they have in common with almost any textile fiber, wool fibers also possess the quality of becoming felted or matted together. This property is a most valuable

FIG. 25 —Cotswold Ram of U. S. A.

one, as it adapts wool to a large number of uses to which other fibers are unsuited.

Silk is also a member of the general group of animal fibers and though it possesses certain general chemical characteristics in common with wool and hair, yet it has an entirely different physiological origin, being a filament of animal tissue excreted by a certain species of caterpillar, and hence is totally different from wool in its physical properties. There is also a distinct chemical difference in wool and silk. The former contains sulfur as an essential constituent, while the latter contains no sulfur in its composition.

2. Different Classes of Hair Fibers.—Wool may be specifically designated as a variety of hair growing on certain species of mammalia, such as sheep, goats, etc. The unmodified term " wool " has special reference to the product obtained from the different varieties of sheep. Cashmere,

mohair, and alpaca are the products obtained from the thibet, angora, and llama goats, respectively. Fur is also a modified form of hair, but differs from wool in many of its physical properties, and is not adapted for use in the manufacture of spun textiles. It is, however, largely employed for the making of hat felts. The cross-section of wool is almost circular, while that of fur is quite elliptical. The fur of the hare, rabbit, and cat is occasionally mixed with cotton, wool, or waste silk and spun into yarns. Such yarns are principally used for the weaving of certain kinds of velvets.

Höhnel states that it is usual to distinguish hairs as down or wool-hair, beard-hair, bristle-hair, brush-hair and quill-hair. The differences between these varieties, however, depend less on actual anatomical relations than on external properties, such as strength, rigidity, thickness, length, form, etc. In order to make this clear, let us take an example: The beard-hairs of rabbit skin in the lower part cannot be distinguished from the true wool-hairs, whereas their points have the same structure as bristles. Furthermore, the fine beard-hair of Newcastle sheep is constructed just like the wool of other thoroughbred sheep; while again, the fur of the hare, beaver, and many other "pelt animals" possesses the same typical structure as the true beard-hairs of thoroughbred sheep. From this it may be seen that the different varieties of hair may be more easily characterised by their external marks than by their comparative anatomy. Down or wool-hairs are thin and white, generally not stiff, but curly. The beard-hairs are more straight and stiff; have sharp points, and are generally thicker and darker than the wool of the same animal. They are also longer than the latter. Beard-hairs and wool together form the fleece. By bristle-hairs is understood short pointed hairs, such as generally occur on the less hairy parts of the animals; for instance, at the ends of the limbs and parts of the head. Brush-hairs are generally solid and possess only a slight marrow; furthermore, they are more cylindrical in form. Quill-hairs are more conical in shape, and are generally either hollow or possess a well-developed marrow.

3. Wool-bearing Animals.—The wool-bearing animals all belong to the order *Ruminantia,* which includes those animals that chew their cud or ruminate. The principal members of this order are sheep, goats, and camels. The sheep belong to the class *Ovidæ,* and occurs in a number of species which vary considerably in form and geographical distribution, as well as in the character of the wool they produce.

The fleeces of certain primitive breeds of sheep have been examined, including Marco Polo's sheep, *Ovis ammon poli.* There are two coats—a summer and a winter one. The former is entirely of hair, more or less pigmented. The latter is double, an outer coat of hair similar to the summer coat, and an inner coat of fine curled wool. In the case of

O. orientalis the fibers of the inner (winter) coat do not form a much entangled mass as in the other cases, but natural locks very similar in form to those of modern commercial wool. The two kinds of fibers, wool and hair, in these primitive fleeces are quite distinct, and no sort or grade of intermediate fiber was found. It is inferred that fibers of intermediate character found in semi-modern fleeces cannot be transitional forms, and the question whether hair and wool are different in origin and development or whether they result from divergent development of a common type of fiber of intermediate character cannot yet be answered.[1]

FIG. 26.—Lincoln Ewe (American).

4. Classification of Sheep.—Broadly considered, naturalists divide the sheep into three different classes:[2]

(*a*) *Ovis aries*, commonly known as the domestic sheep, and cultivated more of less in every country of the world.

(*b*) *Ovis musmon*, occurring native in the European and African countries bordering on the Mediterranean Sea. This sheep is also known as the *moufflon* and is found particularly in the islands of the Mediterranean Sea. It is smaller than the *argali*, which is described below. The fleece is of a short, brownish, furry fiber, though there is also an undercoat of short, fine wool of a gray color.

(*c*) *Ovis ammon*, which includes the wild or mountain sheep (*argali*) to be found in Asia and America. The big-horn sheep of the Rocky Mountains belongs to this class. The argali sheep are large animals as compared with the ordinary domestic

[1] Crew, *Ann. Appl. Biol.*, 1921, p. 164.

[2] Barker states that in the absence of more definite records it is questionable whether the many types of sheep of the present day are the progeny of one common ancestor or have arisen independently. It is probable that in the remote past only one type existed, and that modifications of this type, due to varying environment and selection in breeding, have formed the basis of all our modern sheep.

sheep. The fleece in summer is of a furry character with a reddish brown color; in winter distinct hair of a brownish gray color is developed, with an undercoat of white wool.

Bowman suggests the classification of sheep into the following three divisions, based on the length of the average fibers:

(1) Short, fine, pure-wooled sheep, such as the merino or Southdown.

(2) Medium-staple and cross-bred sheep, such as those from which the fine combing Australian wools are obtained.

(3) Long-wooled, bright-haired sheep, such as Leicester and Lincoln breeds.

FIG. 27.—Southdown Ram (American).

A more detailed classification tha the above is given by Archer, who divides the sheep into thirty-two varieties:

1. Spanish, or merino sheep (*Ovis hispaniæ*).
2. Common sheep (*Ovis rusticus*).
3. Cretan sheep (*Ovis strepsiceros*).
4. Crimean sheep (*Ovis longicaudatus.*)
5. Hooniah, or black-faced sheep of Thibet.
6. Cago, or tame sheep of Cabul (*Ovis cagia*).
7. Nepal sheep (*Ovis selingia*).
8. Curumbar, or Mysore sheep.
9. Garar, or Indian sheep
10. Dukhun, or Deccan sheep.
11. Morvant de la Chine, or Chinese sheep.
12. Shaymbliar, or Mysore sheep.
13. Broad-tailed sheep (*Ovis laticaudatus*).
14. Many-horned sheep (*Ovis polyceratus*).
15. Pucha, or Hindoostan dumba sheep.
16. Tartary sheep.
17. Javanese sheep.
18. Barwall sheep (*Ovis barwal*).
19. Short-tailed sheep of northern Russia (*Ovis brevicaudatus*).
20. Smooth-haired sheep (*Ovis ethiopia*).
21. African sheep (*Ovis grienensis*).
22. Guinea sheep (*Ovis ammon guineensis*).
23. Zeylan sheep.
24. Fezzan sheep.
25. Congo sheep (*Ovis aries congensis*).
26. Angola sheep (*Ovis aries angolensis*).
27. Yenu, or goitered sheep (*Ovis aries steatiniora*).
28. Madagascar sheep.
29. Bearded sheep of west Africa.
30. Morocco sheep (*Ovis aries numidiæ*).
31. West Indian sheep of Jamaica.
32. Brazilian sheep.

These represent the naturally occurring classes of sheep in the different countries; of course, a large number have been emigrated and domesticated in other countries than those in which they had their origin, which has given rise to several subvarieties. Then, too, new varieties have been formed by cross-breeding and intermixing, which has brought about a considerable variation in the type. The latter is also influenced very largely by climatic conditions, geographical environment, and character of pasturage.

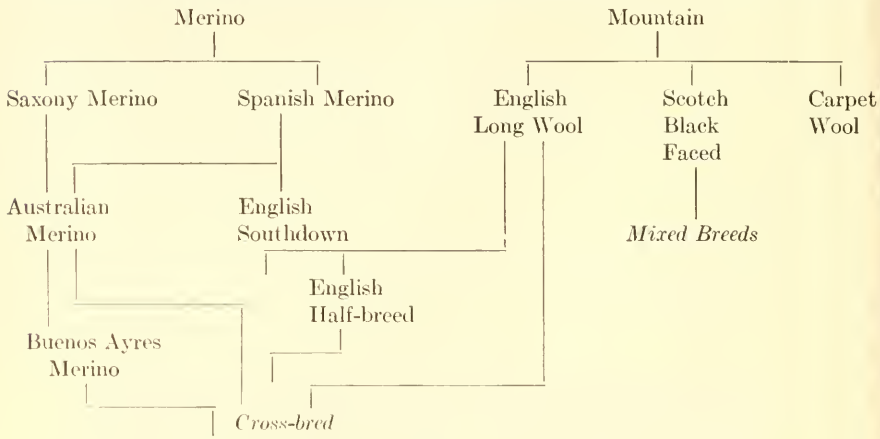
5. The Domestic Sheep.—The domestic sheep is the most important of these classes. It yields by far the greater portion of the wool of commerce. Other varieties, such as the Hungarian sheep, the Zigaja sheep, the Moorland sheep, etc., yield an inferior fleece consisting of a mixture

FIG. 28.—Merino Ram (American).

of wool and beard-hairs. The domestic sheep can hardly be said to be indigenous to any one country, for it appears to have been cultivated by the earliest peoples in history, and it has spread over the entire face of the globe with the gradual extension of civilisation itself. The first actual mention of sheep in England appears in a document of the year 712, where the price of the animal is fixed at one shilling until a fortnight after Easter.

Different conditions of climate and soil, of pasturage and cultivation, appear to exert a considerable influence on the variety of the sheep and on the character of the wool it eventually produces. Variations are also produced by cross-breeding and intermixing, and the nature of the fiber has been much altered and improved by careful selection in breeding and genealogical development.

The following diagram shows the general pedigree of the domestic sheep:



Barker gives a convenient trade classification of British sheep as follows:

(1) *Long Wool Breeds.*—Lincoln, Leicester, Border Leicester, Cotswold, Romney Marsh, Wensleydale, Devon. These wools are characterised by length and luster, and are usually remarkable for strength and soundness. They are typical worsted materials, being straight-fibered and capable of conversion into a parallel fibered yarn of marked smoothness and luster. They are employed mostly for the production of bright fabrics which are durable and possess excellent draping qualities.

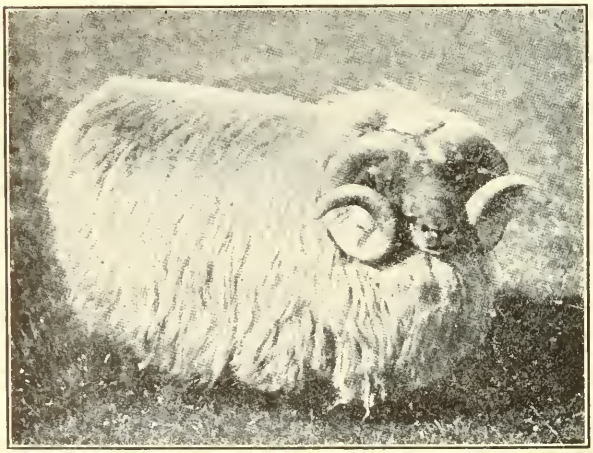


FIG. 29.—Scotch Black-faced Ram.

(2) *Short Wool Breeds.*—Southdown, Shropshiredown, Hampshiredown, Oxforddown, Suffolkdown, Dorset, Ryeland. The main feature of these wools is a firm and clearly defined curliness which makes them particularly suitable for hosiery yarns where fulness and softness are important. The fiber is usually of good color and fine in staple, therefore useful for light-weight goods. These wools are not remarkable for strength and they usually do not felt well. They are employed considerably in woolen fabrics to give fulness and springiness.

(3) *Mountain Breeds.*—Blackface, Herdwick, Cheviot, Louk, Dartmoor, Exmoor, Penistone. These wools are usually bred with less care and, being grown under more severe climatic conditions, lack brightness and are irregular in fiber and staple. Also,

differences in various portions of the fleece are more marked and there is a greater quantity of kemps; hence, these wools give more trouble in sorting and spinning and also in dyeing. The fiber is usually rough and wiry and poor in cohering qualities, hence spins rather poorly and is harsh in handling. They are used for lower-grade thick yarns for both woolen and worsted types. The cheviot wool is the most important of this class, giving its name to a Scotch tweed cloth.

(4) *Highland Breeds.*—Short-tailed, Welsh, Irish. These wools lack character and trueness. With the exception of the Irish wool (which is the best of this class) they are irregular in staple, thick in fiber and contain much kemps, hence spin poorly and give much waste. They are only suitable for thick goods of low quality, and are largely used for flannels, dress-goods and tweeds.

6. Geographical Distribution of Sheep.—The merino sheep, which yields what is considered to be the finest quality of wool, appears to have originated in Spain, and at one time was extensively cultivated by the Moors. The sheep, however, certainly was a domestic animal in Britain long before the period of the Roman occupation; and it is probable that some use was made of sheep-skins and wool. But the Romans established a wool factory whence the occupying army was supplied with clothing, and the value of the manufacture was soon recognised by the Britons.

The Spanish merino sheep consisted of two chief races: (1) The short-legged Nigretti sheep, later known as Infantados, with pronounced neck-folds and a dewlap, and (2) the tall, long-legged Escurial sheep. The Saxon Electoral breed is a derivative of the latter race, while the Austrian Imperial and the French Rambouillet breeds are derivatives of the former. The English breeds of long-wool or luster-wool sheep, including the Lincolns, Leicesters, and Cotswolds, yield fleeces consisting chiefly of beard-hairs.

The exportation of merino sheep from Spain was long guarded against with great care, no one being allowed to take a live merino sheep out of the kingdom of Spain under penalty of death. Later, however, this sheep was brought into various countries, being crossed with the different local breeds with very beneficial results. A German derivative of the Spanish merino known as the Saxony Electoral merino, gives perhaps the highest grade of fiber known in Europe. Australian sheep are mostly derived from merino and other high-class stock and yield a wool of the highest quality. The merino has been cultivated and crossed with other breeds throughout the various parts of the United States, and this country has become a large producer of middle-grade wool. Sheep were introduced at Jamestown in Virginia in 1609 and in 1633 the animals were first brought to Boston. Ten years later a fulling mill was erected at Rowley, Mass. The factory woolen industry, however, was not established till the close of the eighteenth century, and it is recorded that the first carding machine put into operation in the United States was constructed in 1794, under the supervision of John and Arthur Schofield.

7. Australian Wools.—First and foremost of the wool-producing countries of the world is Australia, and although it possesses no indigenous breed of its own, it can be stated without fear of contradiction that no country has been so successful in sheep rearing up to the present stage of the world's history.

The effect of climate upon the growth of wool has been demonstrated very effectively in this country, as may be illustrated from the following facts: The first sheep introduced into Australia came from India, and were of exceptionally poor quality. They possessed a coarse, hairy fleece, and in this respect resembled goats, rather than sheep; but under the influence of the country's splendid climate and pastures, they became very much changed in character, so much so that in the course of a few years they lost all their hair-like growth, and a wool of respectable quality was produced.

This process of migration proved so successful that Southdowns and Leicesters were introduced from England, with very marked success. The later introduction of the merino sheep to Australia, and crossing the breed with the prevailing sheep of the colony, gave the impetus to the development of the industry, which henceforth became the staple trade of Australasia. The millions of sheep which now cover the pastures of New South Wales, Victoria, Queensland, New Zealand, and Tasmania are second to none in the world, some even rivaling the finest Saxony. The wool is fine in fiber and of good color, and besides possessing good spinning properties, it is in great demand for its high milling or felting value. The luster cross-breds that are now produced in Australasia, and especially those of New Zealand, are also worthy of note. As a 56's quality[1] for worsted serges, this wool is very superior; it is of good length, lustrous, and produces a good yield.

In Australia about 75 percent of the wool grown is merino and about 25 percent is cross-bred, and the tendency is for the cross-bred production to increase somewhat, owing to the development of the frozen mutton trade, as the large cross-bred sheep yields valuable meat while the merino does not. In New Zealand the tendency is for cross-breds to supplant merinos altogether, and at the present time, of the wool grown in New Zealand, only about 5 percent is merino. The New Zealand cross-bred wool, however, is unrivaled in strength, soundness, fineness, softness, luster and color. There are many types of sheep employed in crossing and in various degrees, consequently a large range of qualities of wool is produced.

8. European Merino Sheep.—The merino of European cultivation is

[1] This term as used in connection with qualities of wool, means that the fiber is suitable for spinning yarn of count 56. For definitions and comparisons of different sizes see Chapter XXVIII.

of high standard quality, but the supply is a very limited one, so far as exportation is concerned.

Barker gives the following properties of the different types of merino wools:

	Fine.	Medium.	Strong.
Quality	70's to 90's	60's to 64's	58's
Length of staple, ins.	$2\frac{3}{4}$	$3\frac{1}{2}$	4
Fineness, ins	1/1600	1/1200	1/1000 and below
Softness	Very soft	Soft	Fairly soft
Color	Very white	White	Fairly white
Waviness, per inch	26	20	16
Impurities, percent	48 to 52	50 to 54	52 to 56
Appearance	Clearly defined, dense and uniform	Uniform, bold growth and robust	Fairly uniform, open, not distinct
Uses	Cashmeres, Italians, worsted coatings—the short fibers into finest woolens and billiard cloths	Worsted, coatings, dress-goods — the short fibers into woolens, army cloths	Cheaper fabrics, used for blending with cross-breds and for hosiery yarns

It may be mentioned that all merinos are of Spanish origin, and however they may flourish in other parts of the world, it is only fair to state that the quality of the wool that is produced in Spain has not been excelled to any marked degree.

Historical writers tell us that the fleeces of the original Spanish merinos were either wholly or partially brown or black in color, but by careful selection and breeding, white wools were eventually produced. The probability of this statement is evidenced by the fact that we still have naturally colored wools produced, both in Spain and other parts of the world, where Spanish sheep have been introduced and acclimatised. About the year 1723 the Spanish merino was introduced into Sweden, but probably on account of the colder climate, which is not favorable to fine wool growing, it did not flourish. Shortly after, the breed was introduced into France, but not being kept pure, it deteriorated somewhat in quality. In the years 1765 and 1775 they were respectively introduced into Germany and Austria, where they have flourished to a remarkable extent.

Special mention may be made of the German merinos, which by careful attention and breeding, especially in the kingdom of Saxony, have closely rivaled their progenitors of Spain. The wool has a fine soft handle, and is of high spinning and felting value. The Austrian merinos, which are sometimes termed the Negretti or Infantado breed, produce a wool that is inferior to that produced by their German neighbors. It is usually very

thick in the fleece, and often very matted or tangled, while the yolk or grease that it contains is so stiff as to render washing out difficult, but when cleaned it is fairly fine and long.

The merino sheep was introduced into England about the year 1791, but the climate of the country was not compatible with the demands of the breed, and in consequence the quality of the wool could not be preserved, although much advantage was gained by crossing it with native breeds. The merino sheep was introduced into Holland and Belgium about the year 1789, but it has not acquired the same standard of perfection as in Germany, or even Austria.

The wools of Great Britain vary from short to long and are divided into two classes under these terms. The finest British wools grown are the Southdown wools of about 56's quality, while the coarsest are the mountain wools of Scotland and Wales. The Lincoln and Leicester wools are renowned throughout the world as the finest long wools grown. They have a long, wavy staple of good breadth, which is indicative of trueness of breeding. They possess a good luster and are particularly valuable for certain fabrics. The southern uplands of Scotland are among the best sheep regions in the British Islands. In this section there are more sheep per acre than anywhere else in the world.

Russia produces many varieties of wool, mostly of the coarse, hairy type. The Danube provinces produce wool mostly from the Wallachian sheep; it is of a fine, soft character, but its value is lessened by the presence of coarse hairs. It is mostly manufactured locally for cheap apparel fabrics.

Iceland wool is of low quality and forms a species of down at the base of a longer hair covering. It is used chiefly for rugs and blankets. The wools of Norway, Sweden and Denmark are rather coarse and much mixed with strong hair.

9. Sheep of the United States.—Various classes of sheep were introduced into the United States in colonial times. Since their introduction, such developments have taken place that sheep farming has now become one of the important industries. At the present time, there are many first-class flocks scattered over the country that are of distinctly merino handle and finish.

Special mention may be made of the Vermont sheep, which are notable for the heavy weight of fleece they produce. This characteristic has been taken advantage of by some Australian breeders, who, by crossing the Vermont with their own breeds, have secured good results in the weight of the fleeces of what are known as the Australian-Vermont cross-breds.

The State of Wyoming produces a quality of wool that is of good color, and by careful selection could be made into an extremely useful class. The wools of Texas and Arkansas, although of fine and soft handle, are

rather tender and dirty. The States of Oregon, Nevada and Ohio also produce their quota of wool, but although they are useful qualities, they are inclined to be tender and could be much improved.

The United States can use all of the wool it produces, and in fact must import large quantities of foreign wools to supply her needs. No country in the world surpasses some parts of the United States as a field for sheep farming, with its undulating pasture lands, rich in the finest herbage and abundance of water. The fact that sheep can be fed on the green parts of the cotton plant and the cotton-seed cake, after the oil is expressed, has been taken advantage of in the South, and there can be little doubt that America could be made an important wool-producing country in all qualities that can be required.[1]

10. South American Wools.—The majority of the sheep in South America are the offspring of Spanish breeds, which were introduced under the viceroyalty of Spain. The chief breeds are the Buenos Ayres and the Montevideo merinos. The wools produced from these sheep are fine in fiber, but are much contaminated with burrs. The River Platte cross-breds are similar, in many respects, to those of New Zealand, and are employed for similar purposes. Argentine wool is known as B. A. (Buenos Ayres) or River Platte. Uruguayan wool is known as M. V. (Monte Videan). Owing to the natural pasturage being burry and seedy, South American wools are liable to contain a large amount of vegetable matter. The M. V. wools are largely of the merino type, and vary from 58's to 64's in quality. They give a good yield of fiber and are short and loose in staple, and full and spongy in handle, therefore suitable for hosiery and dress-goods of a soft nature. They are also used largely for blending with Australian wools. The B. A. wools are light in mass, thus a B. A. top is about half the weight of a New Zealand top of the same size, being lighter fibered, spongier, and more springy. They are excellent for worsted cross-bred styles as they give more body to the fabric than Australians or New Zealands, but great care must be taken in finishing processes with these wools.

Argentina is also noted for being the sole producer of alpaca from a goat of that name. The fiber is exceptionally silky and of good length with a high luster. The average length of the fiber is about 8 ins. if shorn

[1] Sheep raising for wool fiber, however, in the United States does not seem to be on the increase, but on the contrary the wool production during recent years has been decreasing. The consumption of wool in the United States during 1922 was about 803,000,000 lbs., or somewhat over 7 lbs. per capita. During the same year the United States produced only about 250,000,000 lbs. of wool and consequently had to import about 550,000,000 lbs. In 1913 the United States produced about 300,000,000 lbs. of wool, so that notwithstanding the considerably increased consumption of wool in this country, its cultivation and production has steadily declined.

yearly, and it is grown in various colors, yellowish brown, gray, white and black being the most common. It is made into luster dress-goods and was introduced as a material for textile fabrics by Sir Titus Salt.

11. African Wools.—Cape Colony and Natal, as well as the British Transvaal and Orange River Colony are making much headway as producers of fine merino wools. The wool is very soft to the handle and scours a good white, but the hardness of the epidermal scales of the fiber renders it a very indifferent milling wool. Nevertheless it is a very useful quality, having been much improved during recent years, and it is extensively used for hosiery and knitting yarns for which it is exceptionally well adapted.

Barker states that Cape Colony and Natal are essentially fine wool producing countries, but double clipping is often in evidence, causing the wool to be suitable only for filling and hosiery yarns. Cape wool is very fine and silky, but usually short and of "clothing" quality, yielding from 60's to 70's quality. The yield of pure fiber is often as low as 30 percent, but the wool scours readily and is very white in color. On this account Cape noil is worth more than Australian noil. The fiber of Cape wool is clean in appearance and handle, and is not generally strong, but it suits the clean-faced, slippery handling cloth into which it is made. In Germany it is used in considerable quantities for lace-making. As a milling wool it is very unsatisfactory.

The wool from the east of Cape Colony is a very inferior class, being profusely infested with kemp fibers. This quality is only serviceable for the production of heavy woolen goods, such as blankets and carpets.

The wool of Northwest Africa is very coarse and faulty, due very largely to neglect in its cultivation. In Upper Egypt the sheep are fairly well looked after, and produce a moderately good wool of a medium quality. The native sheep of Morocco, Algiers and Tunis are poorly bred creatures that produce a wool of a coarse and indifferent quality. These results are undoubtedly due to negligence on the part of the natives, as some of the native sheep of Tunis have been imported into Spain and America and crossed with merino sheep with good results.

12. Asiatic Wools.—The Asiatic breed of sheep owe their origin to the wild argali or moufflon sheep of the Asiatic mountains. In Asia the flat-tailed and fat-rumped sheep abound, giving a coarse, rough, matted wool, which is only suitable for carpets and low-grade fabrics. The general characteristics of the domesticated varieties are similar in many respects to those of Palestine and Syria and are coarse and faulty and of indifferent length. They are used principally for low-grade, heavy woolens.

The Persian sheep of Central Asia produce a fine, soft wool which is used by the natives for making fine shawls and carpets.

The different classes of wool produced in Persian Azerbaijan are:

(1) Khoi wool, which is produced in the northwestern part of Azerbaijan, in the districts around Khoi and Maku; (2) Urumiah wool, which is produced southwest of Lake Urumiah, in the Suduz district of Urumiah and Ushnu; (3) Soujbulak wool, produced south of Lake Urumiah; (4) Sakiz wool, produced south of Lake Urumiah; (5) Salmas wool, produced west of Lake Urumiah; (6) Karadagh and Ardabil wools, produced in the northeastern part of Azerbaijan, in the district between Tabriz and the Caspian Sea.

Khoi, Urumiah, Soujbulak, and Sakiz wools are all suitable for use in the manufacture of carpets. Khoi wool is the finest carpet wool produced in the Province, and Sakiz wool the poorest. Khoi is long and of a soft, silky texture. The best Khoi wool is produced in the vicinity of Maku. Urumiah wool is inferior to Khoi wool, and Soujbulak wool is coarser than Urumiah wool. After being washed Soujbulak and Sakiz wools are of practically the same quality, but the unwashed Sakiz wool, which is commonly sold in the market, is dirtier and dustier than unwashed Soujbulak wool.

Salmas wool is short, coarse, and usually red in color. It is not suitable for carpets, and is used by the native population for making clothing and bedding. It is rarely exported from the region in which it is produced. Karadagh and Ardebil wools are also unsuitable for carpets and are almost entirely used by the native population for making clothing and bedding.

Wool is one of the most important economic products of Mesopotamia. Its production is inexpensive, and in normal times it finds a ready market. According to the Director of Agriculture, at Bagdad, wool dealers and exporters of Bagdad recognize three distinct varieties of Mesopotamian wools: "Arabi," "Awassi" and "Karradi." Arabi is the name given to wool from the sheep owned by the Arabs of the plains of Iraq. It is superior to Awassi and Karradi, and compares very favorably with the best wools of India, China and the North Coast of Africa, including Egypt. This wool is exported to England, where it is used in the manufacture of cloth. The best qualities as to strength, fineness, softness and flexibility, waviness or curliness, length and uniformity of staple, luster, etc., are found among the browns and blacks. The whites are poorest in quality and approximate to the Awassi wools. Awassi wool comes from a breed of sheep chiefly owned by the Arabs whose habitat is in the region between Mosul and Aleppo. This breed of sheep is said to be a cross between the Arabi and Kurdish, or Karradi. The wool produced is white in color, is long stapled, coarser and less wavy than Arabi, but superior in all respects to Karradi. Karradi is a commercial name of the wool of the Kurdish sheep bred to the north and west of Mosul on the Kurdish hills. In color it resembles Awassi; it is longish in staple, very slightly curled; the fibers

TABLE OF THE VARIETIES

Varieties and Sub-varieties.	Breed.	Cross.	Staple of Fleece.
1. Spanish (*Ovis hispaniæ* of Linnæus)	Spanish	—	—
	Class 1, Estantes or Stationary	—	Short
	(*a*) Churrah	—	Long (8 ins.)
	(*b*) Merino	—	Short
	Class 2, Migratory	—	—
	Swedish	Merino and native	Long
	French	Merino and Roussillon	"
	Danish	Leonese and native	Medium
	Saxon	Merino and best native	Short
	Prussian	Merino and native	"
	Silesian	"	"
	Hungarian	"	"
	Hanoverian	Merino and small native	"
	New South Wales	Merino and Southdown	—
	"	Merino and Leicester	—
	Victorian	"	—
	W. Australian	"	—
	Queensland	"	—
	New Zealand	"	—
	South American	Merino and Lincoln	—
	South African	"	—
	United States	"	—
	British	Merino and Southdown	Short
2. Common Sheep (*Ovis rusticus* of Linnæus)			
Sub-variety (*a*), Hornless or Lincolnshire	Lincolnshire	Lincoln and Leicester	Long
Sub-variety (*b*), Muggs and Shetland	Shetland	—	"
Sub-variety (*c*), Ryeland	Hereford	—	"
Sub-variety (*d*), Southdown	Sussex	—	Short
	Kent	Southdown and Romney Marsh	"
	Hampshire	Southdown and old black-faced Berkshire	"
Sub-variety (*e*), Old Norfolk	Norfolk	Southdown and Norfolk or Downs	"
Sub-variety (*f*), Old Wiltshire	Wiltshire	Southdown and Wiltshire	"
Sub-variety (*g*), Cornish	Cornwall	Cornish and Leicester	Long
Sub-variety (*h*), Bampton	Devonshire	Bampton and Leicester	"
Sub-variety (*i*), Exmoor, Notts.	Exmoor	Exmoor and Leicester	"
Sub-variety (*j*), Cotswold	Devonshire	Cotswold and New Leicester	"
Sub-variety (*k*), Improved Teeswater	Durham, York	Teeswater and New Leicester	"
Sub-variety (*l*), Silverdale	Lancashire	—	"
Sub-variety (*m*), Penistone	West Riding of Yorkshire	Penistone and Leicester	Short
Sub-variety (*n*), the higher Welsh Mountains	The Mountain Sheep	—	"

OF DOMESTIC SHEEP

Quality.	General Color.	Combing or Carding.	General Application.
—	—	—	Spanish wools obtained from the plains are of the merino kind, and are chiefly used for woolen goods; but that obtained from the mountains is coarse and of unequal quality, and is used for various low-class goods
Fine	Black and white	Carding	
Rather coarse	White	Combing	
Very fine	"	Carding	
—	—	—	
Soft, fine	White	—	
Soft and very fine	"	—	Dress goods and cashmeres
Fine	"	Combing and carding	
Finest	"	"	Broad, West of England, billiard, and fine dress cloths. Silesian wool is almost, if not quite, the finest in the world
Very fine	"	"	
"	"	"	
Fine	"	Carding	—
Very fine	"	—	—
"	"	Combing or carding	Dress goods, coatings, etc.
"	"	"	Meltons and pilots
"	"	Carding	Hosiery
Fine	"	Combing or carding	Serges for suitings and dress goods
"	"	"	
"	"	"	
"	"	"	
"	"	"	Coatings, etc.
"	"	"	Dress goods, etc.
"	"	"	Fine dress goods, broadcloths, etc.
Good and glossy	"	Combing	These are amongst the finest of the long-stapled luster wools; used for lustrous worsteds, braids, etc.
Very fine	—	"	—
Medium	White	"	The finest British wools; used for dress fabrics, serges and flannels, etc.
Fine	White and gray	Combing and carding	
Medium	White	"	
Fine	"	"	
"	"	"	For flannels and low woolens
"	"	"	—
Coarse	"	"	—
Very fine	"	Combing	—
Medium	"	Combing and carding	—
"	"	Combing	Worsted and serges
Fine	—	"	—
Good	White	"	—
Moderate	"	Carding	—
Fine	"	"	Blankets and flannels

TABLE OF THE VARIETIES

Varieties and Sub-varieties.	Breed.	Cross.	Staple of Fleece.
Sub-variety (*o*), Black-faced...	Westmorland	—	Medium
	Cumberland	—	—
	Northumberland	—	—
	Scotland	—	—
Sub-variety (*p*), Hebridean....	The Hebrides	—	Long
Sub-variety (*q*), Shetland.....	Shetland	—	—
Sub-variety (*r*), Wicklow Mountains	The Irish	—	Medium
3. Seling (*Ovis selingia* of Hodgson)	Nepaul, central hilly region, and Eastern Thibet	—	Long
4. Curumbar	Mysore	—	Short
Garar	India	—	"
5. Morvant de la Chine	China	—	"
6. Moroeco (*Ovis aries numidix* of H. Smith)	Moroeco	—	"
7. Yenu, or Goitered Sheep....	Angola	—	"
Sub-variety, Persian	Persian	—	Long
Sub-variety, Fat-tailed	Abyssinian	—	—
Sub-variety, Russian	Odessa	—	Short
Sub-variety, Thibetan	Thibetan	—	—
Sub-variety, Cape	Cape of Good Hope	—	Fur-like
Sub-variety, Buenos Ayres.....	South American cross....	—	—

tend to coarseness, and the fleece staples are matted with locks characteristic of an inferior breed of sheep. Awassi and Karradi wools are exported from Bagdad to America and there used in the manufacture of carpets.

The Thibet sheep of Northern India produce a wool of mixed quality; the finest, after sorting, is used for making fine shawls, as is the fiber from the cashmere goat. The wools of East India, and especially those of Madras, are of very low and coarse quality. They are invariably of a dusty nature, and in consequence give a bad yield. The wools produced are extensively used for blankets and carpets.

China has made rapid progress during the past decade as a wool-producing country. The wool varies from coarse to exceptionally fine and silky, though it seems to possess a tenderness which is not to its advantage. Large quantities of Chinese wools are shipped to America for the heavy woolen trade, though the natives make a fine class of serge from some of the wools they produce.

OF DOMESTIC SHEEP—*Continued*

Quality.	General Color.	Combing or Carding.	General Application.
Coarse	White and gray	Combing and carding	Blankets, carpet yarns, etc.
—	—	—	—
—	—	—	—
—	—	—	—
Inferior	White	Combing and carding	Tweeds, etc.
The finest	"	Carding	—
Medium	—	Carding and combing	Woolen friezes, etc.
Fine	Some breeds black	Carding	East Indian wools are used for rugs, carpets, and blankets
Coarse	White, yellow, gray, brown, black	Carding	Blankets, low tweeds, etc.
"			
Rather coarse, but peculiarly soft and silky to the touch	Yellow	"	Rugs and carpets
Inferior fine and soft	White and gray	"	Felts, rugs and blankets
Fine and close	—	—	—
Medium	White, black, fawn, yellow, brown, gray	Combing	—
—	—	—	—
Fine	—	—	Worsteds
—	—	—	—
—	—	—	Used for fur trimmings
Fine but burry	—	—	Fine woolens, etc.

13. Classification of Fibers in Fleece.—Sheep in their natural condition produce two kinds of hair: the one giving a long, stiff fiber, which we will call "beard-hair"; and the other a shorter, softer, and more curly fiber, which we will designate as "wool-hair," or true wool. By domestication and proper cultivation the sheep can be made to produce the latter kind of hair almost exclusively, with but little or none of the hairy fiber. Herein the sheep differs essentially from the goat, as the latter will always produce both kinds of fiber, though the fineness and quality of its hair may be much improved by proper cultivation. According to Barker[1] wild sheep have two classes of fiber, one of coarse hair showing cell structure and the other of fine wool showing scale structure. It is also found that in normal sheep living under domestic conditions, where nature does not weed out one fiber and leave the other, there is a tendency to grow both coarse and fine fibers with a cell structure which is between hair and wool and is neither the one nor the other. Along with this nondescript fiber

[1] *Jour. Text. Inst.*, 1922, p. 43.

will be found strong fibers with the hair "mosaic" structure and fine fibers with the wool "scale" structure. The different types of fibers are shown in Fig. 30, ranging from the thick, coarse hair fiber of the primitive so-called Marco Polo sheep with the "mosaic" structure on the surface to the fine wool fiber with the overlapping "scale" structure.

In well-cultivated sheep the wool-hairs are usually united in *tufts* or *locks* containing a hundred or more fibers. Often several locks are connected into one large one called a *staple*, the hairs joining the locks together being known as *binders*. The number of hairs growing on each square inch of the sheep's skin is between 4500 and 5500. In addition to the above-mentioned varieties of hair, most sheep grow more or less short, stiff hairs, or undergrowth; these have no value as textile fibers. It must

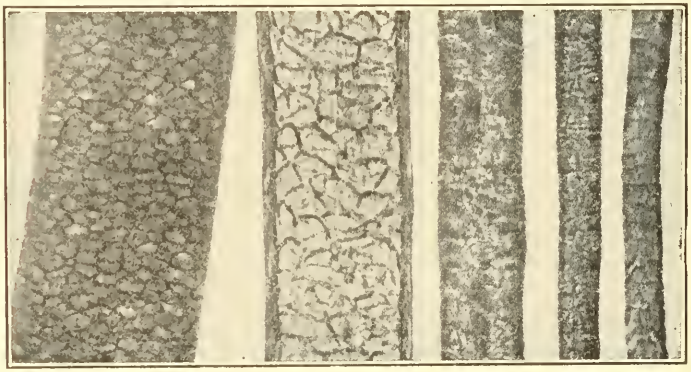


Fig. 30.—Variations in Wool Structure: (1) Hair from Marco Polo sheep; (2) Hair from black-faced sheep; (3) Nondescript fiber from same; (4) Fiber changing toward wool; (5) True wool fiber. (Barker.)

be mentioned, however, that the exact character of the wool on the individual sheep varies considerably with its position in the fleece; on the extremities of the animal the wool becomes more hairy in nature, and near the feet the short undergrowth of stiff hair is alone to be found.

14. Wool-sorting.—The texture, length, and softness of the fiber differ considerably in different portions of the fleece. Hence it becomes necessary, in order to obtain a homogeneous mixture of fibers with properties as constant as possible, to sort out the fibers of the fleece into different portions, which are put together into different grades of wool stock. This operation is termed *wool-sorting* and *grading*, and is an important step in the manufacture of wool. The wool-sorter works at a table or frame covered with a wire netting through which dirt and dust fall as he handles the wool. Fleeces which have been hard-packed in bales, especially if unwashed, go into dense, hard masses, which may be heated until the

softening of the yolk and the swelling of the fibers make them pliable and easily opened up. When the fleece is spread out the stapler first divides it into two equal sides; then he picks away all straws, large burrs, and tarry fragments which are visible; and then with marvelous precision he picks out his separate qualities, throwing each lot into its allotted receptacle. Sorting is very far removed from being a mechanical process of selecting and separating the wool from certain parts of the fleece, because in each individual fleece qualities and proportions differ, and it is only

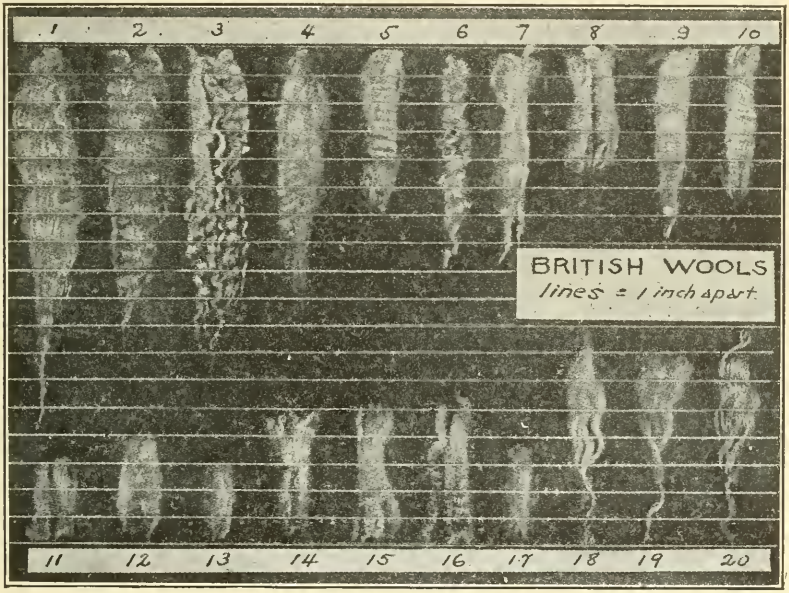


FIG. 31.—British Wools: (1) Nottingham; (2) Lincoln; (3) Yorkshire; (4) Notts Forest Hog; (5) Notts Forest Wether; (6) Gloucester; (7) Lincoln half-bred Hog; (8) Lincoln half-bred Wether; (9) Irish Hog; (10) Irish Wether; (11) Southdown Wether; (12) Southdown Teg; (13) Shropshire Wether; (14) Shropshire Hog; (15) Super Stafford Wether; (16) Super Stafford Hog; (17) Welsh Wether; (18) Welsh Hog; (19) Scotch Blackface; (20) Scotch. (Tetley.)

by long experience that a stapler is enabled, almost as it were by instinct, rightly to divide up his lots so as to produce even qualities of raw material.

Different varieties of wool may require different systems and degrees of sorting, but in general the fleece is roughly divided into nine sections, given as follows:

(1) The shoulders and sides of the fleece give the finest and most even staples of fiber. This wool possesses the best strength, length, softness, and uniformity combined.

(2) The lower part of the back yields a fiber of fairly good staple, and somewhat stronger.

(3) The loin and back give a shorter staple, and the fiber is not as strong and liable to be sandy.

(4) The upper part of the legs give a staple of moderate length. The fiber on this part is frequently in the form of loose, open locks and acquires a large amount of burrs by brushing against "stickers" and the spinose fruit of plants; the presence of these burrs considerably lessens the commercial value of the wool. South American wool is especially liable to be heavily charged with burrs.

(5) The upper part of the neck gives a rather irregular staple which is also very frequently filled with burrs, and liable to be kempy.

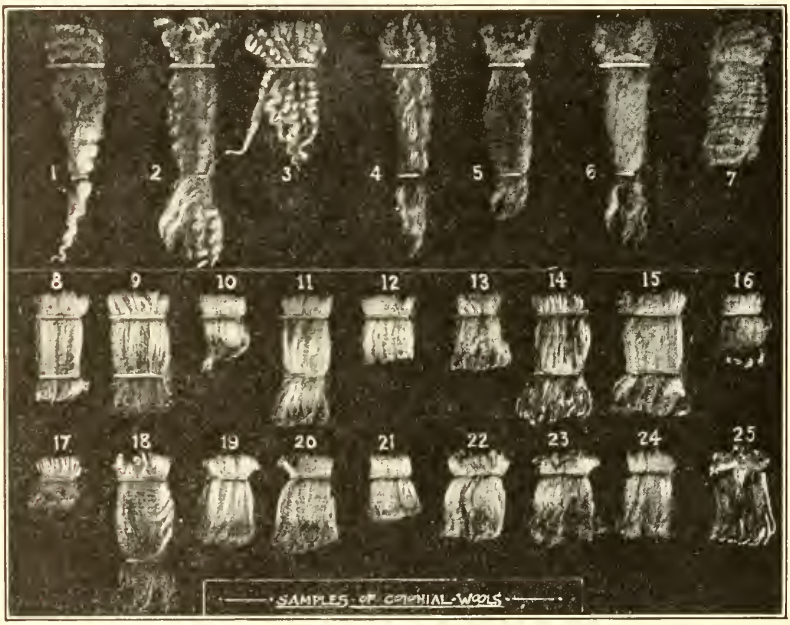


FIG. 32.—British Colonial Wools: (1) New Zealand clean dry hogs; (2) New Zealand half-breds; (3) New Zealand greasy cross-bred lambs; (4) Buenos Ayres 44/46's Hogs; (5) Buenos Ayres 59's; (6) Geelong fine cross-bred hogs; (7) Geelong greasy half-bred; (8) Choice New South Wales; (9) Cooimbil New South Wales; (10) Sydney lambs' edges; (11) Geelong super combing; (12) Geelong lambs' extra super; (13) Geelong good stylish clean; (14) Swan River; (15) Swan River good ordinary combing; (16) Swan River dark growth; (17) Adelaide lambs; (18) Adelaide greasy; (19) Cape Colony Steynburg; (20) Cape Colony Graf Reinet; (21) Cape Colony Adelaide; (22) Orange River Colony Winburg; (23) Orange River Winburg; (24) O. B. C. Dewetsdorp; (25) O. R. C. Harrismith. (Tetley).

(6) The center of the back gives a fine delicate staple similar to that from the loins.

(7) The belly, together with the wool from the fore and hind legs, yields a poor staple and a weak fiber.

(8) The tail gives a short, coarse, and lustrous fiber, frequently containing a considerable amount of kemps.

(9) The head, chest, and shins give a short, stiff and straight fiber, opaque and dead white in color.

"Rigging" is a term applied to the manner in which the fleece is divided through the middle of the back from the neck to the tail portion. This method of division is shown diagrammatically in Figs. 31 and 32.

According to E. W. Tetley (*Textile Manufacturer*), who describes the English practice of sorting wool, all wools narrow down into certain definite standard qualities, and it is the best way for testing purposes so to consider them. The quality of a wool indicates the probable worsted counts of yarn to which it will spin. Thus a 40's quality would spin a 40's yarn—that is, a yarn having 40 hanks of 560 yds. each in 1 lb., or 22,400 yds to 1 lb. It will be seen, however, that these quality numbers are, except in the finest wools, well above the actual spinning counts. The

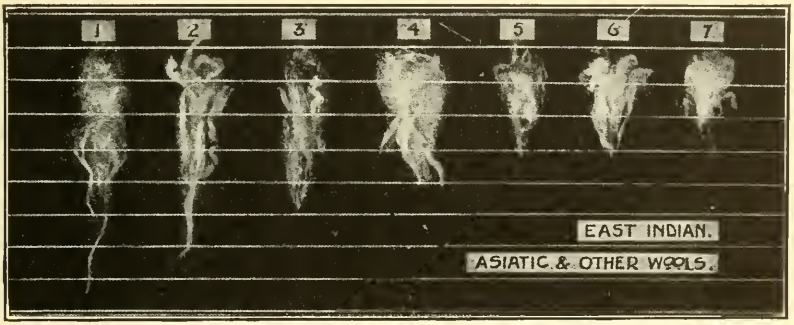


FIG. 33.—Asiatic and African Wools: (1) Donskoij; (2) Egyptian; (3) Morocco; (4) Coarse East Indian; (5) Georgian; (6) Chinese; (7) Bagdad. These types are hairy in character. (Tetley.)

following lists show from what kinds of wool the various qualities are obtained:

BRITISH WOOLS

28's to 32's: *Mountain Types.*—Scotch blackface wethers and hogs; Irish, Scotch, and Herdwick ewes and wethers.

32's to 36's: *Mountain.*—Irish mountain, best Scotch cross wethers and hogs. *Lusters.*—Lincoln wethers and hogs, Nottingham wethers, Yorkshire wethers. *Demi.*—Deep Radnors.

36's to 40's: *Lusters.*—Nottingham hogs, Leicester wethers and hogs, Ripon wethers, Devons, Yorkshire hogs. *Demi-lusters.*—Selected Irish wethers, super Staffordshire wethers. *Demi.*—Welsh fleeces, seconds.

40's to 44's: *Lusters.*—Ripon hogs, North wethers. *Demi-lusters.*—Irish wethers (pick and super), Irish hogs (selected), Kent wethers (selected), super Staffordshire hogs. *Demi.*—Welsh fleeces best, Lonk ewes and wethers, Cheviot wethers.

44's to 46's: *Demi.*—North hogs, Irish hogs (pick and super), Kent tegs (selected) half-bred hogs, Norfolk half-bred hogs, fine Radnors, Cheviot hogs (super).

46's to 50's: *Demi.*—Pick Shropshire hogs and wethers, selected Welsh Eastern Counties Down ewes and tegs, Hampshire and Oxford Down ewes and tegs.

50's to 58's: *Demi.*—Wiltshire and Dorset Down tegs and ewes, Southdown tegs and ewes.

These British wools may be thus summarised:

Mountain Wools.—Length 8 ins. to 1½ ins., strength deficient, no luster, color according to soil; handle harsh, brittle, non-felting, more or less kempy; yield 55 to 70 percent according to soil; fineness 28's to the best of 50's quality.

Luster Wools.—Length up to 16 ins., very strong and firm, high luster, color according to soil, non-felting; yield 60 to 75 percent according to soil; fineness 28's up to 44's quality.

Demi-luster.—E.g., a cross between Lincoln (pure luster) and Shropshire (non-luster). Length up to 8 ins. or 10 ins., strong and firm, "softish" handle, felting indifferent; yield 60 to 70 percent; fineness up to 48's quality.

Half-breds.—Same characteristics as Demi.

Demi (in the sense of non-luster).—Length up to 4 ins. or 5 ins., comparatively strong, soft handle, felting fairly good; yield 60 to 68 percent; fineness up to 54's quality, except Southdowns, which go up to 58's, and are the best.

COLONIAL AND OTHER CROSS-BRED WOOLS

32's to 40's: *Coarse Cross-breds.*—12 ins. downwards, fairly strong and lustrous, harsh, felting indifferent; yield 60 to 70 percent.

40's to 50's: *Medium Cross-breds.*—10 ins. downwards, very strong and lustrous, fairly fine and soft, fair felting properties; yield 55 to 65 percent.

50's to 58's: *Fine Cross-breds.*—6 ins. downwards, very strong, fair luster and good color, soft handle, good felting properties; yield about 50 to 60 percent.

COLONIAL AND OTHER MERINO WOOLS

58's to 64's: *Strong Merinos.*—4 ins. downwards, very strong, good white color, very soft handle, very good felting properties; average yield 40 to 50 percent.

64's to 80's: *Fine Merinos.*—3 ins. downwards, very strong and white, extra soft, with best felting properties; average yield 45 to 50 percent.

As regards the chief wools of other than British origin, this list may be summarised as:

Australasian.—The best types, Port Philip being extra high class.

South American.—Only reach about 60's quality, being deficient in strength and uniformity.

Cape (South African) are also inferior, and reach about 64's. They are singularly indifferent to felting. It must be again noted that these inferior classes are rapidly improving by increased care and attention to breeding.

In England there are two methods of sorting generally employed. The first is known as the *Bradford method,* in which the fleece is divided into two portions which are termed the "rigs" of the fleece. The terms employed in sorting fleeces for woolen qualities are as follows: (1) *Pick-lock,* selected from the shoulders; (2) *Prime,* from the sides; (3) *Choice,* from the middle of the back; (4) *Super,* from the middle of the sides;

(5) *Seconds,* from the lower part of the sides; (6) *Downrights,* from the neck; (7) *Abb,* from the hind legs; (8) *Britch,* from the haunches; (9) *Brokes,* from the edges of the fleece; (10) *Shorts* and *Pieces,* from the edges of the fleece in merinos and fine cross-breds (see Figs. 34 and 35).

The following are definitions of common wool terms: *Lamb's Wool.*—Up to seven months old. *Hog.*—First clip off sheep, about one year old. *Teg.*—Same as hog, in shorter wools. Both hogs and tegs are naturally finer and longer than wethers, and are thus classed about four qualities higher. *Wether.*—After first clip. *Ram* and *Ewe* are, of course, male and female respectively, the former producing longer and stronger wool. *Comeback* refers to the wool from a sheep which after crossing and recross-

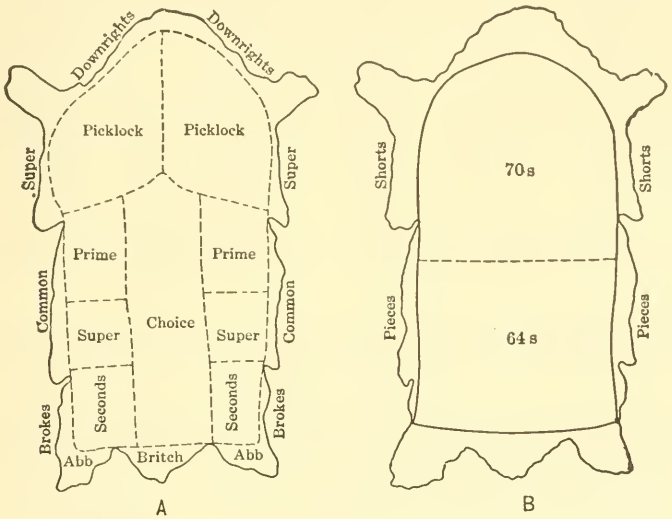


FIG. 34.—(*A*) Diagram of Woolen Sorts; (*B*) Diagram of Merino 64's to 70's Quality.

ing comes back nearly to the original breed or type. *Super* is finer than *Selected,* and *Pick* finer than *Super.*

The second method of sorting is the *Scotch method,* in which the fleece is sorted whole, and the different portions into which it is divided are termed "*matchings,*" these are known by different terms: (1) *super* is the finest portion of a demi-luster fleece; (2) *fine* is the best part of the shoulders of a fine luster fleece spinning from 40's to 44's counts; (3) *blue* is from the shoulders of an ordinary luster fleece (Lincoln and Leicester); (4) *neat* is from the sides of an ordinary luster fleece spinning from 32's to 34's; (5) *brown* is mostly from the flanks; (6) *britch,* from the tail and thighs; and finally (7) *cow-tail,* the lowest matching from the long-wooled fleeces.

In fine English wools there are two further matchings: *extra diamond* from the shoulders of an English "down" fleece, and spinning 54's to 56's; and *diamond*, which is from the sides of the same fleece. *Brokes* is a term used to designate the skirting or edge of the fleece; it is always used for woolen yarns.

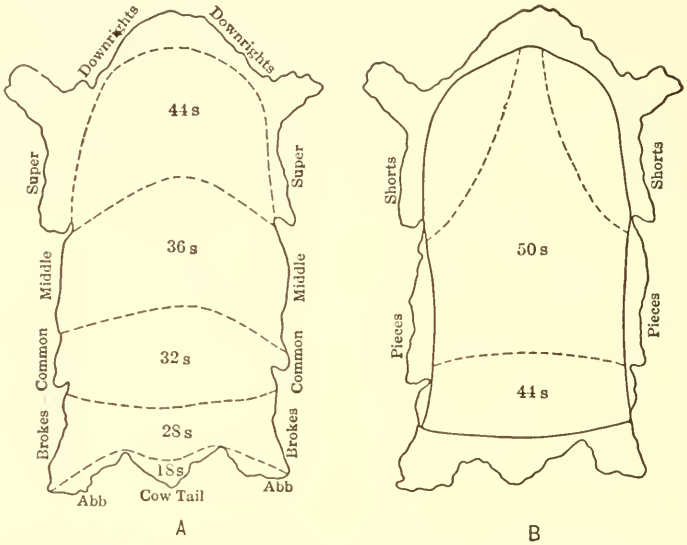


FIG. 35.—(*A*) Diagram of Lincoln Hog 18's to 44's; (*B*) Diagram of New Zealand Cross-bred 50's Bulk.

The following table[1] shows the approximate amounts of the different qualities contained in a pack (240 lbs.) of fleeces:

Quality.	Lincoln Hogs, Pounds.	Leicester Hogs, Pounds.	Irish Hogs, Pounds.
Fine matchings	17.57	33.90	34.13
Blue matchings	149.03	139.96	144.30
Neat matchings	45.37	44.18	40.46
First brokes	5.80	5.19	4.87
Second brokes	7.31	5.03	5.76
Third brokes	2.67	2.68	3.54
Britch	7.99	6.00	4.49
Tail	1.31	0.36	0.60
Cotts	0.31	1.76	1.24
Gray	0.03	0.02	
Toppings	1.45	0.65	0.50
Waste	1.16	0.30	0.12

[1] *Text. Mfr.*, 1908, p. 185.

As a rule, the coarser the fleece the wider the variation in the fibers; some fleeces contain as many as fourteen qualities, whereas others have only two or three. Merinos are often used in an unsorted condition, after being classed and skirted in the country from which they come, the staples being of a remarkably uniform nature throughout the entire fleece. The sorting of English wools usually necessitates a general classification of the fleeces into two lots of hogs and wethers respectively. The hog wools are usually of finer quality and may be recognised by the taper points of the fibers indicating a first clip; wether wool, on the other hand, is square ended on account of being a subsequent clip.

The first shearing from a two-year old sheep is known as *hog* (or hogget) wool, while that shorn from a sheep which has been previously clipped is known as *wether* wool. The finer qualities of hog wool are sometimes known as *teg* wool. In hog wool the natural end, or point, of the fiber is preserved whereas in wether wool both ends are sheared.

15. Character of Fleece.—The amount of fiber in the fleece varies greatly with the breed, sex, age, and racial conditions of the animal. The average yield from the ewe is 1.75 to 4 lbs, and from the wether 3.5 to 7.5 lbs.

According to Barker, the following table gives the approximate weights of fleece carried by different varieties of sheep:

Breed.	Weight of Fleece.
Merino (Australian)	6 lbs.
Merino (South American)	6.5 "
Merino-Lincoln	8 to 10 "
Southdown	6 "
Lincoln	12 "
Shetland	4 "
Cashmere	4 ozs.

In 1885 the average weight of wool per sheep per year was about 5 lbs., while in 1911 from 7 to 8 lbs. was the average weight.

The bulk of wool comes into commerce in the form of *fleece wool*, the product of a single year's growth, cut from the body of the living animal.[1] The first and finest clip, called *lamb's wool*, may be taken from the young sheep at about the age of eight months. When the animal is not shorn until it attains the age of twelve or fourteen months, the wool is known as hog, or hogget, and like lamb's wool, is fine and tapers to a point. All

[1] *Virgin wool* is a term which has arisen in the consideration of various "Truth-in-Fabric" forms of legislation, and is used to distinguish wool direct from the fleece from recovered wool obtained from manufactured fabrics, such as shoddy, etc. Hence virgin wool may be taken to include fleece wool, pulled wool, slipe wool, or, in fact, any wool that has not previously been manufactured into yarn or cloth.

subsequent cut fleeces are known as wether wool, and possess relatively somewhat less value than the first clip. Fleece wool, as it comes into the market is "in the grease," that is, unwashed, and with all the dirt which gathers to the surface of the greasy wool present; or it is received as *washed wool*, the washing being done as a preliminary to the shearing; or, in a few cases, it is scoured, and is consequently known as *scoured wool*.[1] *Skin wool* is that which has been removed by a sweating process. The worst type of skin wool, known as *slipe*, is removed from the skins by lime, which naturally affects the handle of the wool and renders it difficult to bring into a workable condition later.

Skin and slipe wools have increased considerably of late years owing to the development of the frozen mutton trade. The sheep-skins of Australia, New Zealand and South America are mostly dealt with from special centers of trade, the chief of which is Mazamet, France. If sodium sulfide has been used for de-wooling the skins, the wool is generally known as a Colonial skin wool.

The sweating process of de-wooling skins consists in the development of bacterial action resulting in the destruction of the soft connecting tissue between the outer skin and the under skin and also of the roots of the fiber. In the lime method the soft gelatinous matter in the skin is dissolved, and as the agent acts on the wool side of the fleece, useful portions of both wool and skin are dissolved. The sulfide method depends on the power of sodium sulfide to dissolve the wool fiber and the outer skin without affecting the skin proper, therefore it is applied from the inside of the skin, and the action must be carried on only to the point where the fiber roots are attacked so that the wool may be readily pulled from the skin. A new method for de-wooling skeep-skins is by burning the fiber off with an electrically heated wire; it is claimed that the skin is left intact and the wool fiber is equal in quality to sheared wool. The method, however, does not seem to have come into general commercial use.

Skin wools that have been obtained by the "lime" method of pulling will always contain a considerable amount of lime, in some cases as much

[1] According to Barker, about three-fourths of the wool imported into England is shipped "in the grease"; a very small and diminishing proportion is "fleece washed," and the remainder is "scoured." The fleece washing may be effected either on the sheep's back or in the fleece form after shearing, the fleece being run over rollers and subjected to a spray of warm water. As far as manufacturing centers are concerned, wool is preferred in the grease, due to the fact that scoured wool is frequently discolored and felted. Cape wool, however dirty, should always be shipped in the grease, as the fiber is so fine, soft and curly that after press-packing in the scoured state it cannot be opened and re-washed without considerable injury. It is stated that merino wools can be better judged in the grease, while luster wools can be better judged in the washed state. Most of the wools grown in England are washed on the sheep's back.

as 8 percent, and as each pound of lime will render useless about 15 lbs. of soap, it will readily be seen that wool of this character will not be desirable. Clean, dry, combed tops will absorb from a clear saturated solution of lime-water as much as 2 percent of its weight of lime (CaO).

Wool is also classified as *clipped* (or fleece) and *pulled* wools; the former is cut from the living sheep and forms the greater part of the wool appearing in trade; it is divided into long and short staple, or combing and clothing wools. Pulled wool is pulled by the roots from the pelts of dead sheep. *Clothing wools* are used for broadcloth and heavy cloth, the combing wools for the thinner fabrics for women's wear. *Medium wool* is used for worsted goods, alpacas, mohairs, etc., while the coarser wools go into carpets, blankets, and the like.

There are certain terms distinctive to American wools. *Delaine wool* generally means the Ohio merino and the finer crosses, and the delaine wool of Ohio is considered the strongest merino wool in the world. *Territory wool* is usually applied to wool from west of the Mississippi River, while *fleece wool* is a term applied to wools grown east of the Mississippi River.

16. Commercial Grades of Wool.—The table on pages 66 and 67 given by Radcliffe and Clarke, of the various commercial grades of wool, though somewhat similar to the preceding tables, differs in certain particulars.

17. Carpet Wool.—Carpet wool is a coarse variety of wool. Some is obtained from Argentina, in which country it is known as *criollo* (creole or native) wool. In America it is called cordova (or cordoba) wool. Owing to admixture of the native breed with the merino, however, a finer fiber is now generally produced, and on this account the production of carpet wool in Argentina has been decreasing. The creole wool is largely used in Argentina, for the making of mattresses, as it retains its elasticity more than other wools. Carpet wools are also obtained from Russia, Asia Minor, Persia and China. They are long, coarse and hairy in character, usually without much luster and with little waviness.

18. Statistics of Wool Production.—According to estimates made by the *Market Reporter* (1920) the total annual world production of wool is 2,800,000,000 to 3,000,000,000 lbs. One estimate divides the merino, cross-bred, and low wools as follows:

	Lbs.
Merino	869,000,000
Cross-bred	1,135,000,000
Low wool	890,000,000
Total	2,894,000,000

COMMERCIAL GRADES OF WOOL

Variety.	Breed.	Quality.	Staple.	Uses.
Spanish	Leonese and Sorians (Merino)	Fine	Short	Fine worsteds and woolens
Silesian	Merino and also Cross-bred	Super fine	"	Broadcloths
Saxony		Very fine	"	West of England and fine dress cloths
Australian	Merino, Queensland	Fine	"	Fine worsteds and woolens
"	New South Wales and Victorian	Very fine, good color	"	Meltons, pilots and fine worsteds
"	South Australian	Fine, moderate color	"	Fine worsteds and woolens
"	Western Australian	Fine, usually contains brown fibers	"	" " " "
"	Tasmanian Australian	Very fine	"	Fine milled fabrics and half milled worsteds
"	Australian and Lincoln Cross-bred	Medium Demi Luster	Medium	Fine worsted serges
"	" and Leicester Cross-bred	" " "	"	" " "
"	Australian and Southdown Cross-bred	Average fine, good color	"	Hosieries and fine flannels
"	Australian Vermont Cross-bred	Fine heavy fleece	Short	Fine worsteds and woolens
New Zealand	Cross-bred with Lusters	Moderate fine and lustrous	Average	Serges and worsteds
British	Lincoln	Good, strong and lustrous	Long	Worsteds, serges, braids
"	Leicester	From medium to coarse	"	Fabrics with raised face and hosieries
"	Southdowns	Finest British wool	Short	Flannels, fine blankets, hosieries
"	Norfolk Downs	Fine	"	Light dress goods
"	Suffolk	"	"	" " "
"	Dorset	"	"	Livery cloths and woolens
"	Romney Marsh	Medium, fairly lustrous	Average	Serges and carpets
"	Yorkshire	Long and lustrous, good color	Long	Demi luster worsteds
"	Nottingham	Strong medium luster	"	Worsted serges and baizes
"	Shropshire	Moderate fine, good color	Medium	Medium worsteds
"	Staffordshire	" " " "	"	" "
"	Gloucester (Cotswold)	Medium	Long	Worsted cord and serges
"	Cheviot	Medium to coarse	Medium	Cheviot serges
Welsh	Soft Wooled	Fine but kempy	"	Flannels and blankets
"	Mountain	Coarse and kempy	Long	Carpets and coarse worsteds

Irish	Soft Wooled (Galway)	Good color	Medium	Flannels and medium worsteds
"	Mountain (Wicklow and Kerry)	Coarse and kempy	Long	Tweeds and cords, friezes
Scotch	Blackface	Medium to coarse	"	Tweeds, blankets and carpets
"	Orkney and Shetland Isles	Indifferent milling wools	Short to medium	Hosieries, serges
South American	Buenos Aires, Merino	Very fine but burry	Short	Worsteds and woolens
" "	Monte Vidian	" " " "	"	" " "
" "	B. A. Cross-bred	Medium and moderate luster, rather blue	Long	Worsted serges and woolens
" "	M. V. Cross-bred	Medium and moderate luster, rather blue	"	" " " "
" "	Alpaca (Arequipa fleece)	Finest, very lustrous	Moderate length	Luster dress goods
" "	Alpaca (Uruguayan fleece	Fine and lustrous	" "	" " "
" "	Peru (Wool)	Indifferent length and kempy	Various	Blankets and medium woolens
United States	Merino	Average to fine	Short to medium	Fine worsteds and woolens, used chiefly in United States
Canadian	Merino (half cross-bred)	Average	Short	Worsted and woolens and hosieries
"	Ontario Cross-bred	Medium to coarse, dirty	Long	Serges, worsted and woolen
South of France	Merino of Rousillon Cross	Soft and fine	Medium to short	Dress goods and cashmere
North of France	Cross-breds	Medium	Medium	Worsteds and woolens
Algeria	Native Sheep	Inferior	Indifferent	Blankets, low tweeds, carpets
Indian	Native Eastern (Madras)	Coarse to kempy	Medium to short	Blankets, felts, rugs
"	Horniah	Medium to coarse	Medium	Native shawls and blankets
"	Kandahar	Medium	"	Shawls and low worsteds
"	Joria	"	"	" " " "
Russian	Odessa	Fine, good color	Short	Worsteds
"	Merino (Crimean)	Very fine	"	Broadcloths and fine woolens
"	Astrakhan	Curly and furlike	"	Astrakhan cloths, trimmings
"	Camel Hair	Inferior	Medium	Low carpet yarns
South African	Merino (Graaf Reinch)	Fine, good color	Short	Heavy coatings
" "	Native (West African)	Coarse and inferior	"	Hosieries, knitting yarns, carpets and low woolens
" "	Mohair (Angora)	Medium moderate luster	Long	Luster dress goods, trimmings, plushes
Iceland	Native	Fine roots, coarse tips	Medium	Woolens, not extensively used
Chinese	Morvant de la Chine	Medium to fine silky	"	Blankets, rugs, carpets
Turkish	Smyrna	Inferior	"	Native rugs and carpets
"	Mohair (Van)	Fine, good luster and color	Long	Plushes, luster dress goods, trimmings
Persian	Kerman	Fine	Short	Fine dress goods similar to cashmere
"	Bagdad	Medium to coarse, mixed colors	Medium	Carpets and blankets

Of the merino wools, more than half, perhaps 60 percent, is produced in countries of the British Empire and less than 10 percent in South America. North America is estimated to produce from 15 to 20 percent of the world's crop of merino wools. Of the cross-breds, South America produces more than 30 percent and the countries of the British Empire about 40 percent. The low wools come largely from Russia, China, and other eastern countries.

Some idea of the relative production of the various countries may be obtained from the following summary (1920) of the world's sheep:

United Kingdom	29,000,000
Other European countries	151,000,000
Total	180,000,000
Australasia	103,000,000
Asia	93,000,000
North America	55,000,000
South America	96,000,000
Africa	65,000,000
Total world	592,000,000

In 1895 there was an estimated total of 522,000,000 sheep.

SUMMARY OF THE WORLD'S WOOL PRODUCTION (1919)

	Lbs.
Australasia	742,000,000
South America	470,000,000
North America	318,000,000
Europe—	
United Kingdom	125,000,000
Russia in Europe	320,000,000
France	65,000,000
Germany	26,000,000
Italy	22,000,000
All other	240,000,000
Total	798,000,000
Asia	273,000,000
Africa	208,000,000
World's total	2,809,000,000

UNITED STATES WOOL PRODUCTION [1] (1919)

Year.	No. of Sheep.	Production, Pounds.	Imports, Pounds.	Total Production and Imports, Pounds.
1910	52,448,000	321,000,000	180,000,000	501,000,000
1911	53,633,000	319,000,000	156,000,000	475,000,000
1912	52,362,000	304,000,000	238,000,000	542,000,000
1913	51,482,000	296,000,000	152,000,000	448,000,000
1914	49,719,000	290,000,000	260,000,000	550,000,000
1915	49,956,000	286,000,000	413,000,000	699,000,000
1916	48,625,000	288,000,000	449,000,000	737,000,000
1917	47,616,000	282,000,000	421,000,000	703,000,000
1918	48,603,000	299,000,000	454,000,000	753,000,000
1919	48,866,000	314,000,000	446,000,000	760,000,000
1920	48,615,000			

The number of sheep in this country has decreased by about 4,000,000 during the last ten years. Imports of wool for the five-year period from 1910 to 1914 were less than half of the five-year period following. The total of production and imports has been fairly steady since 1915. The above table shows that the production of wool has not increased in this country during the last decade.[2]

[1] There seems to be considerable variation in the statistics of sheep and wool production in the United States according to the figures compiled by different departments or trade organisations. The statistics for 1914 are given as follows by one of the trade associations:

Number of sheep	31,904,416	
Average weight per fleece	6.8	lbs.
Wool	216,950,028	lbs.
Pulled wool	47,400,000	lbs.
Total clip	264,350,028	lbs.

Prices in Boston Market.	January 1, 1914, Cents per Pound.	January 1, 1915, Cents per Pound.
Unwashed Ohio delaines	22@23	25@27
Quarter-blood, Ohio	24@25	28@30
B Supers (scoured basis)	41@42	58@60
Fine medium, clothing territory (scoured)	50@52	55@58
Fine staple territory (scoured)	53@55	58@60
Jorias (in the grease)	29@31	33@35

[2] According to estimates of the U. S. Department of Agriculture the wool production for the Western States in 1920 was as follows:

	Production, Pounds.		Production, Pounds.
Arizona	15,000,000	Nevada	10,000,000
California	12,000,000	Oregon	13,000,000
Colorado	9,000,000	Wyoming	34,000,000
Idaho	21,000,000	Utah	16,000,000
New Mexico	15,000,000		

ARGENTINA—NUMBER OF SHEEP AND EXPORTS OF WOOL

Year.	Number of Sheep.	Exports of Wool, Pounds.
1895	74,000,000	
1908	67,000,000	387,200,000
1910	.....	332,000,000
1914	43,000,000	258,500,000
1915	44,000,000	259,400,000
1917	45,000,000	298,773,000
1918	.....	256,613,000

Argentina seems to show a decrease, or at least a stationary condition similar to that existing in the United States.

AUSTRALIA—NUMBER OF SHEEP, PRODUCTION OF WOOL AND EXPORTS TO UNITED STATES

Year.	Number of Sheep.	Production, Pounds.	Exports to United States, Pounds.
1910	91,700,000	.....	28,000,000
1912	92,900,000	663,000,000	14,000,000
1914	85,100,000	711,000,000	29,000,000
1916	69,700,000	551,000,000	115,000,000
1918	79,900,000	573,000,000	65,000,000
1919	86,700,000	652,000,000	46,000,000

From data given by *Commerce Reports* the United States for the year ending July 30, 1920, imported raw wool to the value of $212,848,568, and manufactured wool to the value of $43,537,552. During the same year this country exported wool manufactures to the value of $56,223,360. For the year 1919 the amount of wool in the United States available for consumption (including both domestic growth and imports) was 6.8 lbs. per capita.

The following tables prepared by the U. S. Department of Agriculture (1922) show the production of wool (computed on a grease basis) in the various countries of the world (the figures for 1922 are furnished by the Department of Commerce):

WORLD PRODUCTION OF WOOL

Countries.	Average Annual Pre-war Production.	Production in		
		1920.	1921.	1922.
NORTH AMERICA.	Pounds.	Pounds.	Pounds.	Pounds.
United States	314,110,000	302,207,000	224,564,000	261,095,000
British North America	11,210,000	24,422,531	24,050,000	19,125,000
Mexico	7,000,000	750,000	500,000	792,000
Total	332,320,000	327,379,531	249,114,000	281,012,000
Central America and West Indies	1,000,000	750,000	750,000	750,000
SOUTH AMERICA.				
Argentina	358,688,000	308,560,000	286,000,000	231,483,000
Brazil	35,000,000	27,000,000	27,000,000	27,000,000
Chile	17,430,000	33,069,000	33,069,000	31,500,000
Peru	9,940,000	9,420,000	12,000,000	15,000,000
Falkland Islands	4,324,000	3,200,000	3,200,000	3,200,000
Uruguay	156,968,000	100,000,000	95,000,000	80,000,000
All other	5,000,000	5,000,000	5,000,000	5,000,000
Total	587,350,000	486,249,000	461,269,000	383,183,000
EUROPE.				
Austria	15,360,000	.....	.....	1,250,000
Belgium	1,060,000	825,000	1,205,000	825,000
Bulgaria	23,700,000	17,802,000	17,636,000	17,637,000
Czecho-slovakia	.....	5,952,420	5,952,420	4,303,000
Denmark	3,508,000	3,508,000	3,508,000	1,323,000
Finland	.....	3,250,000	3,250,000	8,300,000
France	80,688,000	39,400,000	39,400,000	38,220,000
Germany	25,600,000	37,278,242	42,975,000	51,809,000
Greece	14,000,000	16,000,000	16,000,000	13,420,000
Hungary	26,240,000	25,516,000	25,516,000	9,370,000
Iceland	1,980,000	1,980,000	1,980,000	1,980,000
Italy	35,000,000	50,000,000	50,000,000	50,000,000
Netherlands	3,556,000	5,500,000	5,500,000	4,400,000
Norway	8,160,000	7,247,000	7,247,000	4,409,000
Poland	.....	6,724,000	6,724,000	6,725,000
Portugal	10,000,000	6,232,000	6,232,000	7,717,000
Rumania	13,228,000	13,228,000	14,000,000	18,032,000
Russia and Esthonia (1922)	320,000,000	150,000,000	150,000,000	163,224,000
Spain	52,000,000	142,000,000	165,347,000	165,347,000

WORLD PRODUCTION OF WOOL—*Continued*

Countries.	Average Annual Pre-war Production.	Production in		
		1920.	1921.	1922.
EUROPE—*Continued.*	Pounds.	Pounds.	Pounds.	Pounds.
Sweden	6,060,000	5,354,000	5,354,000	6,613,000
Switzerland	1,049,000	1,049,000	800,000	800,000
Turkey	28,000,000	.....	.....	—
United Kingdom	150,000,000	100,000,000	101,100,000	103,217,000
Jugoslavia	25,446,000	48,859,000	23,800,000	24,251,000
Others	.....	.....	.....	15,000,000
Total Europe	844,635,000	687,705,057	693,527,250	712,345,000
ASIA.				
British India	60,000,000	60,000,000	60,000,000	60,000,000
China	50,000,000	50,000,000	50,000,000	61,320,000
Persia	12,146,000	12,146,000	12,146,000	12,146,000
Russia in Asia	60,000,000	45,000,000	45,000,000	45,000,000
Turkey in Asia	90,000,000	60,000,000	60,000,000	60,000,000
All other	1,000,000	1,000,000	1,000,000	1,000,000
Total	273,146,000	228,146,000	228,146,000	239,466,000
AFRICA.				
Algeria	35,221,000	33,184,000	33,184,000	35,155,000
British South Africa	157,761,470	127,176,800	127,176,800	187,000,000
Tunis	3,735,000	3,735,000	3,735,000	6,765,000
All other	13,000,000	13,000,000	13,000,000	19,175,000
Total	209,717,470	177,095,800	177,095,800	248,095,000
OCEANIA.				
Australia and Tasmania	705,146,000	536,541,757	631,290,000	618,475,000
New Zealand	198,474,000	181,480,000	167,153,000	175,000,000
Australasia	903,620,000	718,021,757	798,443,000	793,475,000
All other	100,000	100,000	100,000	—
Total	903,720,000	718,121,757	798,543,000	—
Grand total	3,151,888,470	2,625,447,145	2,608,445,050	2,684,153,000

The following tables from the U. S. Census Reports (1922) show the magnitude of the wool industry in the United States:

Kind.	Wool Manufactures.		Woolen Goods.		Worsted Goods.		Carpets and Rugs.		Felt Goods and Wool-felt Hats.	
	1919.	1914.	1919.	1914.	1919.	1914.	1919.	1914.	1919.	1914.
Cards, number	8,203	7,800	4,618	3,811	2,457	2,521	592	760	536	708
Woolen	5,835	5,382	4,503	3,753	333	469	463	465	536	695
Worsted	2,143	2,153	20	6	2,041	1,959	82	179	....	9
Cotton	225	255	95	52	83	93	47	116	....	4
Spindles	5,242,613	5,006,286	1,888,213	1,604,881	3,087,916	3,117,151	233,226	246,762	33,258	37,492
Woolen	2,201,666	1,914,691	1,853,014	1,545,195	179,536	229,822	135,898	103,948	33,218	35,726
Worsted	2,988,855	3,010,145	20,371	46,792	2,883,132	2,838,801	85,312	122,786	40	1,766
Cotton	52,092	81,450	14,828	12,894	25,248	48,528	12,016	20,028		
Mule spinning	2,761,180	2,485,790	1,764,133	1,476,095	837,312	872,626	126,788	102,238	32,947	34,831
Woolen	2,079,628	1,815,698	1,761,433	1,470,489	166,420	208,140	118,868	102,238	32,907	34,831
Worsted	681,552	669,926	2,700	5,440	670,892	664,486	7,920	....	40	
Cotton	.....	166	.....	166						
Frame spinning	1,676,139	1,643,583	48,432	46,792	1,555,135	1,485,070	72,572	110,090	....	1,631
Woolen	31,305	9,771	23,513	8,304	.....	864	7,792	300	....	303
Worsted	1,601,602	1,555,228	12,311	27,560	1,531,551	1,435,678	57,740	90,662	....	1,328
Cotton	43,232	78,584	12,608	10,928	23,584	48,528	7,040	19,128		
Doubling and twisting	805,294	876,913	75,648	81,994	694,469	759,455	33,866	34,434	311	1,030
Woolen	90,733	89,222	68,068	66,402	13,116	20,818	9,238	1,410	311	592
Worsted	705,701	784,991	5,360	13,792	680,689	738,637	19,652	32,124	....	438
Cotton	8,860	2,700	2,220	1,800	1,664	.....	4,976	900		
Looms	85,495	86,641	29,894	26,366	45,835	49,462	9,256	10,341	510	472
Wool combing machines	2,294	2,425	26	20	2,171	2,285	85	114	12	6
Pickers	1,223	1,392	954	1,061	103	140	66	89	100	102
Garnett machines	211	221	126	127	29	38	21	30	35	26

FIBERS USED IN THE WOOL INDUSTRY

Material.	Pounds.		Percent of Total.		Percent Distribution.	
	Woolen-goods Industry.	Worsted-goods Industry.	Woolen-goods Industry.	Worsted-goods Industry.	Woolen-goods Industry.	Worsted-goods Industry.
Total	203,133,831	201,403,010	100.0	100.0	50.2	49.8
Scoured wool (equivalent)	86,547,717	177,288,745	42.6	88.0	32.8	67.2
Wool waste and noils	38,522,138	3,300,640	19.0	1.6	92.1	7.9
Recovered wool fiber	49,081,630	2,224,011	24.2	1.1	95.7	4.3
Purchased	31,416,145	1,747,551	15.5	0.9	94.7	5.3
Made for consumption	17,665,485	476,460	8.7	0.2	97.4	2.6
Animal hair	12,613,937	15,667,157	6.2	7.8	44.6	55.4
Mohair, camel, alpaca and vicuña noils	1,738,489	176,974	0.8	0.1	90.8	9.2
Cotton	14,629,920	2,745,483	7.2	1.4	84.2	15.8

LEADING PRODUCTS OF WOOL BY BRANCHES OF INDUSTRY

Product.	Total.	Woolen Goods Industry.	Worsted Goods Industry.	Carpet and Rug Industry.	Felt Goods Industry.	Wool-felt Hat Industry.
Total value	$1,234,657,092	$364,896,590	$700,537,482	$123,253,828	$39,229,540	$6,739,652
Woven goods for personal wear	710,466,849	287,030,146	422,131,592	1,143,826	161,285	
Carpets and rugs	110,151,089	7,591	27,520	110,116,978		
Other woven goods (blankets, carriage robes, etc.)	31,338,008	28,765,972	1,352,085	505,939	714,012	
Felt goods	37,843,349	1,321,234	.....	.....	36,522,115	
Wool-felt hats	5,574,974	.....	.....	.....	.....	5,574,974
Yarns	237,971,867	31,337,200	205,697,251	394,109	43,307	
Wastes and noils	25,040,863	940,381	23,859,344	209,521	31,617	
All other products	57,494,082	10,235,571	33,841,352	10,681,168	1,733,578	1,002,413
Contract work	18,776,011	4,758,495	13,628,338	203,287	23,626	162,265

CHAPTER IV

PHYSICAL STRUCTURE AND PROPERTIES OF WOOL

1. Physiology and Structure of Wool.—Wool, in common with all kinds of hair, is a growth originating in the skin or cuticle of the vertebrate animals, and is similar in its origin and general composition to the various other skin tissues to be found in animals, such as horn, nails, feathers, etc. Wool is an organised structure growing from a root situated in the dermis or middle layer of the skin, its ultimate physical elements being several series of animal cells of different forms and properties. Herein it differs essentially from silk, which is not composed of cells, but is a continuous and homogeneous tissue.

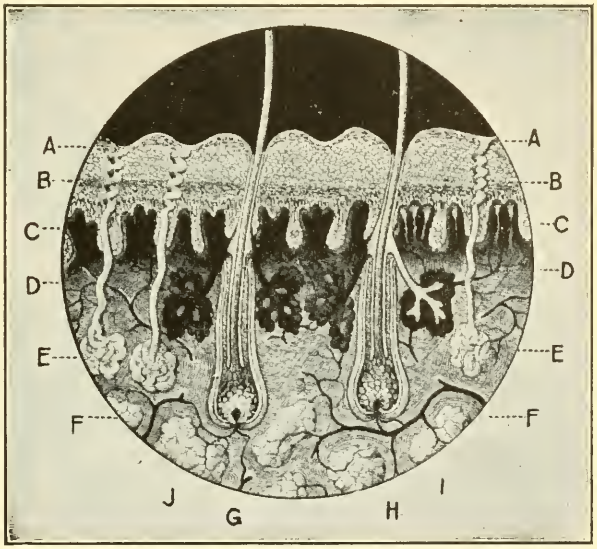


FIG. 36.—Section of Skin: (*A*) Cuticle; (*B*) Rete mucosum; (*C*) Papillary layer; (*D*) Corium; (*E*) Sudoriparous glands; (*F*) Fat cells; (*G*, *H*) Hair follicles; (*I*, *J*) Oil glands. (Bowman.)

The root of the wool fiber is termed the hair follicle (Fig. 36); it is a gland which secretes a lymphlike liquid, from which the hair is gradually developed by the process of growth.[1] The hair follicle also secretes an oil, which is supplied to the fiber during its growth and serves the purpose of lubricating its several parts, giving it pliability and elasticity.

[1] If the form of a hair is considered, it will be noticed at the base to have an egg-shaped swelling or root, and just above this a rather contracted portion or neck. The hair attains its greatest breadth usually in its uppermost third. The majority of hairs show considerable differences in appearance when examined along their length (Höhnel).

In conjunction with the hair follicle there also occur in the skin numerous sebaceous glands which secrete a fatty or waxy substance, commonly known as wool-fat. This substance gradually exudes from the glands and coats the surface of the wool in rather a considerable amount (Fig. 37). It affords a protective coating to the fiber which serves to preserve the latter from mechanical injury during its growth, and also prevents the several fibers from becoming matted and felted together. In the preparation of wool for manufacture, this fatty covering has to be removed, the operation constituting the ordinary process of wool scouring, the object

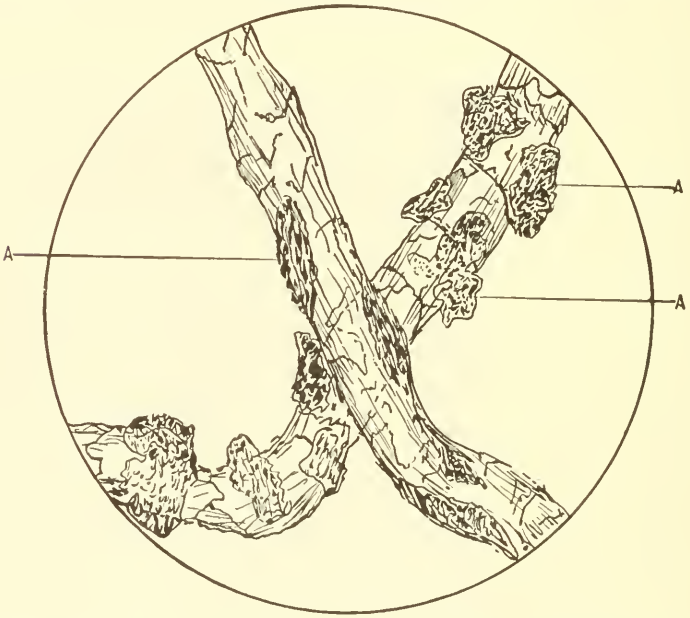


FIG. 37.—Wool Fiber in the Grease. (×500.) (*A*) Irregular lumps of grease and dirt; also note that outline of scales is very indistinct. (Micrograph by author.)

being to leave the fiber clean and free from adhering substances (Fig. 38). There is also a wool-oil which is contained in the cells of the fiber itself, and is a true constituent of its substance. This oil should not be removed, as its removal causes the fiber to lose much of its elasticity and resiliency. The oil amounts to probably about 1 percent of the total weight of the fiber, whereas the external fatty matters amount on an average to about 30 percent.

2. Morphology of Wool Fiber.—Morphologically considered, the wool fiber consists of several distinct portions: (*a*) A cellular marrow, or medulla, which frequently contains more or less pigment matter to which the wool owes its color; (*b*) a layer of cellular fibrous substance or cortical tissue

which gives the fiber its chief strength and elasticity; (*c*) an outer layer, or epidermis, of horn tissue, consisting of flattened cells, or scales, the ends of which generally overlap each other, and project outward, causing the edge of the fiber to present a serrated appearance (Fig. 39). This scaly covering gives the fiber its quality of rigidity and resistance to crushing strain; it also helps the fibers to felt together on rubbing against one another by the interlocking of the projecting edges of the scales.

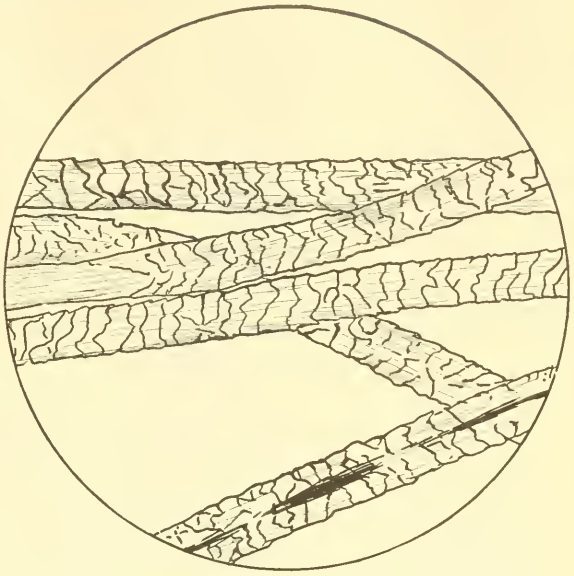


FIG. 38.—Typical Wool Fibers after Removal of Grease. (×350.) (Micrograph by author.)

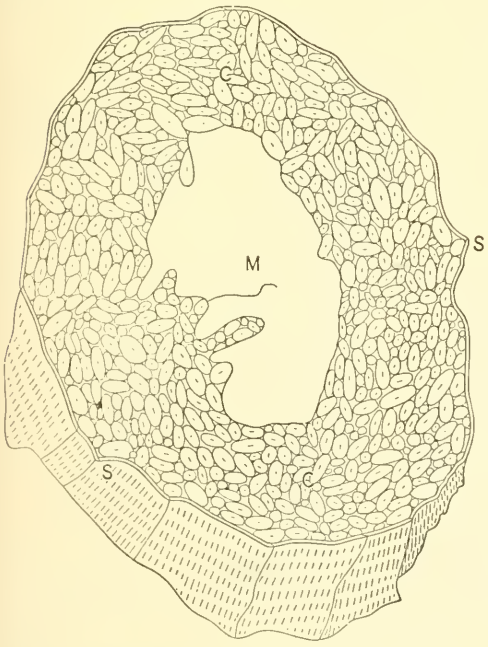


FIG. 39.—Diagram Showing Structure of Wool Fiber: (*M*) Medulla or marrow; (*C*) Cortical Cells; (*S*) Scales or Epidermis.

According to L. A. Hausman (*Scientific American*), hairs have their origin in the bases of relatively deep pits in the epidermis, or outermost layer of the skin, known as hair follicles, and, being added to from the base, push upward in a rodlike growth, of circular or elliptical cross-section. The hair shaft consists of four structural units: (1) the medulla, commonly termed the pith from its analogous structure in plant stems, which is built up of many superimposed cells or chambers, and contains air spaces and sometimes small masses of pigment material; (2) the cortex, or shell, surrounding the medulla, and composed of many elongate,

fusiform cells, coalesced together into a horny homogeneous mass, of hyaline texture and appearance; (3) the pigment granules, to which the

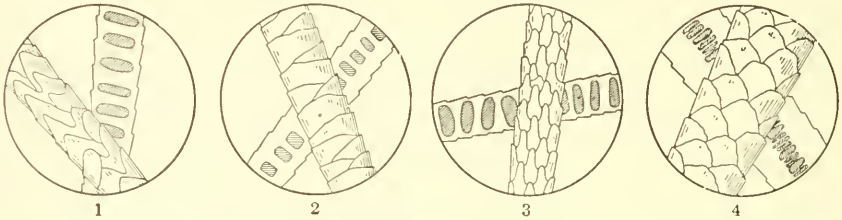


Fig. 40.—Various Hair Fibers: (1) Hare; (2) Gray squirrel; (3) Domestic cat; (4) Badger. (Hausman.)

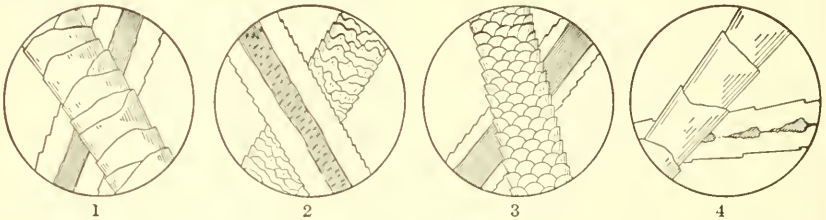


Fig. 41.—Various Hair Fibers: (1) Cow; (2) Horse; (3) Virginia Deer; (4) American Beaver. (Hausman.)

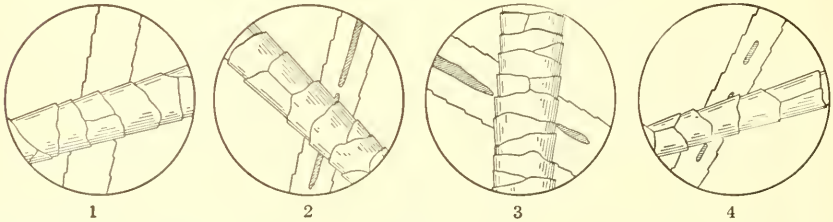


Fig. 42.—Various Hair Fibers: (1) Bactrian Camel; (2) Guanoco; (3) Alpaca; (4) Vicuña. (Hausman.)

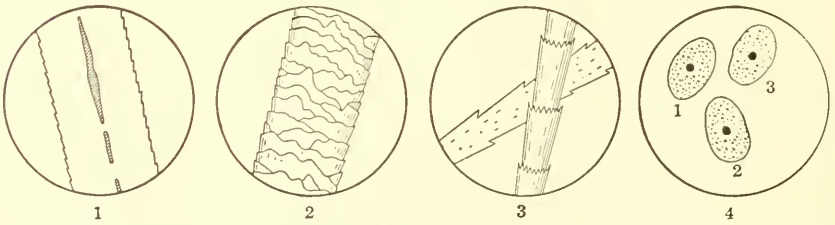


Fig. 43.—Various Hair Fibers: (1) Man, Caucasian female; (2) Same, showing surface scales; (3) Bat; (4) Cross-sections of human hair showing pigment cells.

color of the hair is primarily due, scattered about within the corticular substance; (4) the cuticle, or outermost integument of the hair shaft, lying upon the cortex and composed of imbricated scales.

Medullas fall into four groups: (1) the discontinuous, as in the hair of the domestic cat (Fig. 40, No. 3); (2) the continuous, as in the hair of the cow (Fig. 41, No. 1); (3) the interrupted, a type intermediate between the first two, as in the hair of the horse Fig. 41, No. 2); and (4), the fragmental, as in the hair of the vicuna (Fig. 42, No. 4). It will be noted that the hair of some species apparently lacks the medulla altogether,

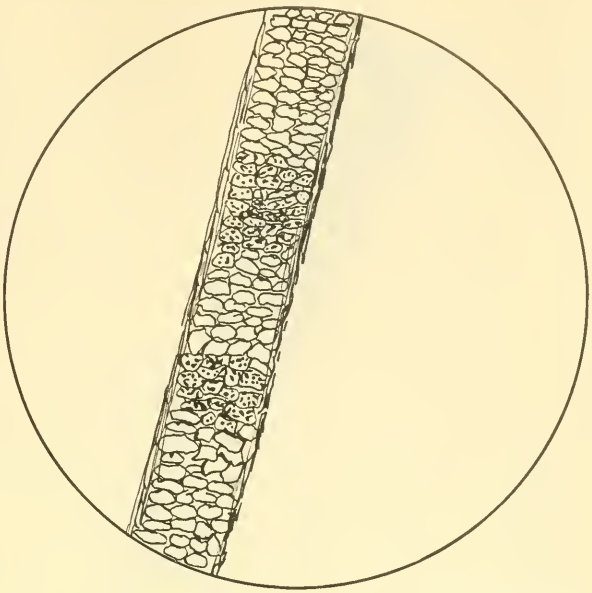


FIG. 44.—Beard-hair of Doe. (×350.) Showing small development of cortical layer and large medulla. (Micrograph by author.)

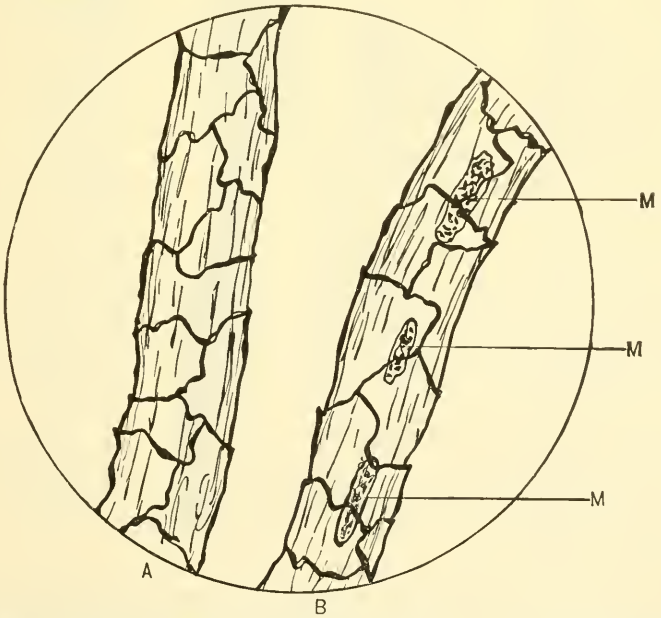


FIG. 45.—Wool Fibers Deficient in Medullary Cells. (×500.) (*A*) a fiber without evidence of medullary cells; (*B*) a fiber showing isolated medullary cells at *M*. (Micrograph by author.)

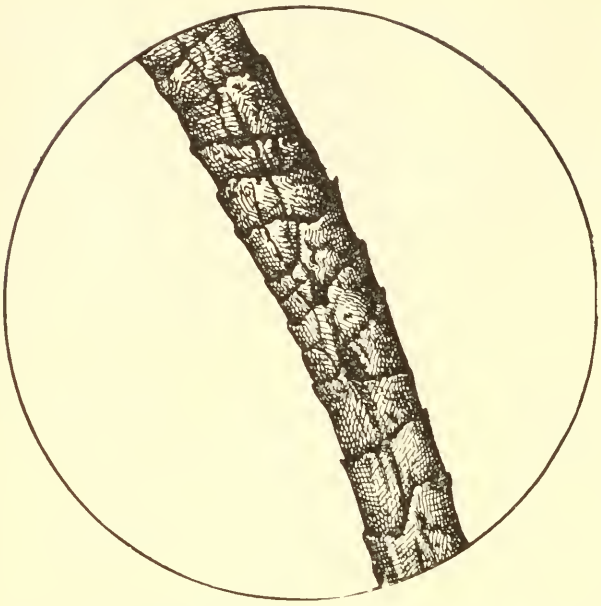


Fig. 46.—Typical Wool Fiber. (×500.)

though minute dissociated traces exist in certain portions of the hair shaft.

The cuticle and its component elements, the scales, are of two diverse types: (1) the imbricated interrupted type, those which lie singly overlapping upon the hair shaft, like the shingles on a roof or the scales on a fish, as in the hair of the badger (Fig. 40, No. 4); and (2) the imbricated coronal type, which encircle the hair shaft as continuous bands, building up the cuticle somewhat like a pile of tall tumblers set one within the other, as in the hair of the intermediate bat (Fig. 43, No. 3).

Of these two primal types there are a multitude of intricate variations. The surface hairs of a large number of mammals are of two kinds: a soft, dense, short, fine hair, called the under or fur hair, and a longer,

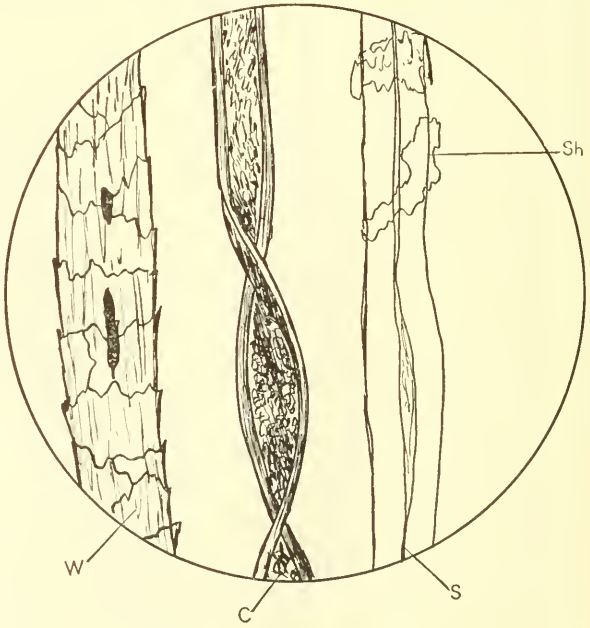


Fig. 47.—Comparison of Wool, Cotton, and Silk Fibers. (×500.) *W*, wool fiber, showing marking of scales; *C*, cotton; *S*, silk, showing irregular shreds of silk-glue at *Sh*. (Micrograph by author.)

coarser, stiffer, sparser growth which projects beyond and overlies the fur hair.

Any one of its physical constituents may at times be lacking in a wool fiber. When the epidermal scales are absent, they have simply been rubbed off by friction; this condition is frequently to be found at the ends of long beard-hairs. The cortical layer of fibrous tissue is frequently but slightly developed, especially in cases where the medulla is large; in some instances, indeed (as in the hair of the doe, Fig. 44), the cortical layer appears to be totally absent in the broadest parts of the fiber. The medulla is very frequently absent, or, at least, shows no difference in structure from the cells of the surrounding cortical layer (Fig. 45); this occurs more especially in the wool-hairs, but is also to be found in beard-hairs. The Zigarra wool of southern Hungary has beard hairs which show no evidence of medullary cells. On the other hand, the medulla is occasionally more largely developed than the cortical layer, and becomes the principal part of the fiber, as in the beard-hairs of the doe.

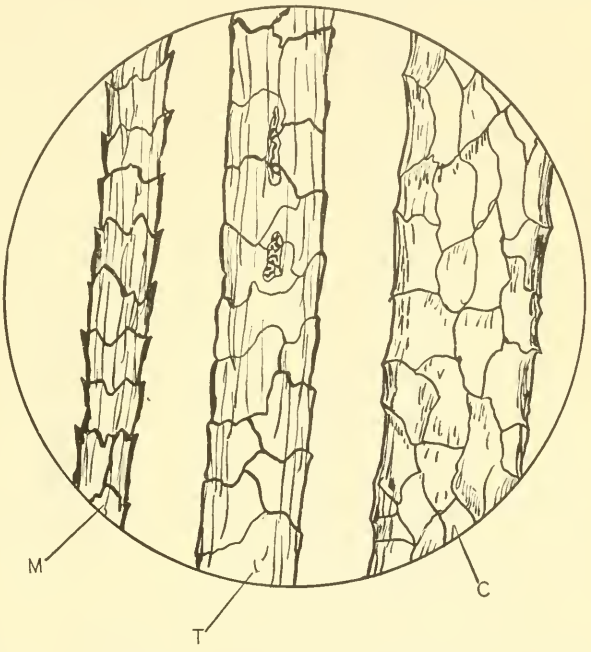


Fig. 48.—Comparison of Different Varieties of Wool. (×500.) *M*, merino wool with only a single scale in circumference of fiber; *T*, territory wool with two or more scales; *C*, coarse wool with numerous scales. (Micrograph by author.)

3. Microscopy of Wool.—The microscopic appearance of wool is sufficiently characteristic to distinguish it from all other fibers. Under even moderately low power of magnification the epidermal scales on the surface of the fiber can be readily discerned (Fig. 46), while neither silk nor the vegetable fibers present this appearance (Fig. 47). The scales are more or less translucent in appearance, and permit of the under cortical layer being seen through them. The exact nature, structure and arrangement of the scales differ considerably with different varieties of wool. In

fine merino wools, for instance, the individual scales are in the form of cylindrical cusps, one somewhat overlapping the other; that is to say, a single scale completely surrounds the entire fiber (Fig. 48, *M*). In some varieties of wool, on the other hand, two or more scales occur in the circumference of the fiber (Fig. 48, *T*). In some cases the edges of the scales are smooth and straight, and this appears to be especially characteristic of fine qualities of wool; the coarser species, on the other hand, possess scales having serrated wavy edges. Usually such scales are much broader than they are long and are very thin. The length of the free or projecting edge of the scale is also a very variable factor; in some wools the scale is free from the body of the fiber for about one-third of the length of the former, and in consequence the scale protrudes to a considerable extent; such wool would be eminently suitable for the preparation of material which requires to be much felted. In other wools the free edge of the scale amounts to almost nothing, and the separate members fit down on one another closely, and are arranged like a series of plates. Wools of this class are more hairlike in texture, being stiffer and straighter, and not capable of being readily felted (Fig. 49). The wool-hairs (the long, stiff fibers which have previously been mentioned as occurring to a greater or lesser degree in nearly all wools, and also known as beard-hairs) usually possess this structure. The felting quality of wool is much increased by treatment with acid or alkaline solutions, or even boiling water; the effect being to open up the scales to a greater extent, so that they present a much larger free margin and consequently interlock more readily and firmly. Woolen yarns, and woven materials made from such yarns, felt much more easily than worsted yarns, due to the fact that the fibers of the former lie in every direction and the interlocking of the scales takes place more easily.

In some varieties of wool fiber the scales have no free edge at all, but the sides fit tightly together with apparently no overlapping; in such fibers the surfaces of the scales are also more or less concave (Fig. 50). This structure only occurs with thick, coarse varieties of wool. Frequently at the ends of the wool fiber, where the natural point is still preserved (as in the case of lamb's wool from fleeces which have not been previously sheared), the scales are more or less rubbed off and the under cortical layer becomes exposed (Fig. 51, *P*); this appearance is quite characteristic of certain wools. In diseased fibers the epidermal scales may also be lacking in places, causing such fibers to be very weak at these points (Fig. 51, *D*).

In most varieties of wools the scales of the epidermis may be readily observed even under rather low powers of magnification, while under high powers the individual scales may be seen overlapping one another like shingles on a roof, and showing pointed thickened protuberances at the

edges. When the fiber becomes more hairlike in nature, such as mohair, alpaca, camel-hair, etc., it is more difficult to observe the individual scales, as these fuse together to a greater or lesser degree, until the true hair fiber is reached, which exhibits scarcely any markings of scales at all under ordinary conditions. By treatment with ammoniacal copper oxide, however, the interscalar matter is dissolved away, and even with true hair the scaly nature of the surface may be observed.

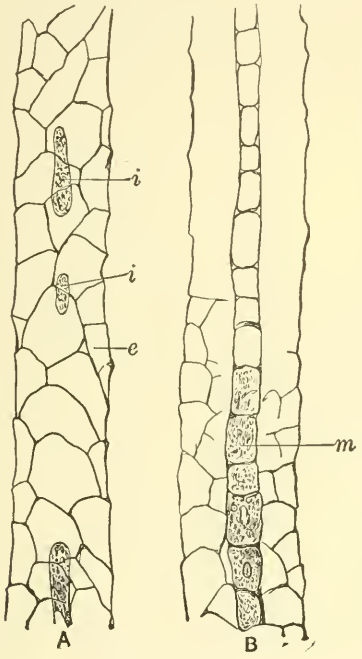


FIG. 49.

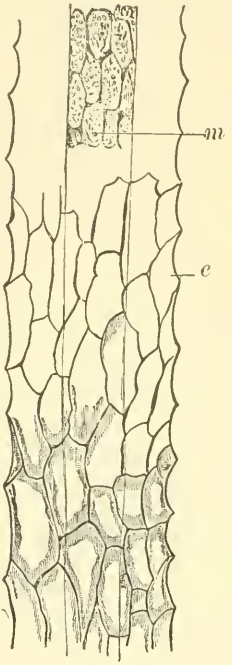


FIG. 50.

FIG. 49.—Wool Fiber with Plate-like Scales. (×340.) (Höhnel.) *A*, portion of fiber with isolated medullary cells at *i*, and smooth scales *e* fitting together like plates; *B*, portion of fiber showing medullary cylinder at *m*.

FIG. 50.—Wool Fiber with Concave Scales. (×340.) (Höhnel.) *m*, medullary cylinder consisting of several rows of cells; *e*, concave scales arranged in a plate-like manner.

In the microscopical examination of hair and wool it is best to treat the fiber with water, as this causes it to swell somewhat and renders the histological characteristics more distinct. As natural hairs are generally greasy from adhering fat, it is usually necessary to first cleanse them by treating with hot alcohol or with ether, and after this the fiber is treated with warm distilled water. According to Höhnel a medulla-free human hair when treated with water swells in diameter about 10 percent, a white

alpaca hair about 13 percent, an angora hair 10 percent, and a cow-hair about 16 percent. In general the hairs without medulla appear to swell about 10 to 11 percent and those possessing a medulla about 15 to 16 percent. Owing to the swelling of hairs in this manner, microscopic measurements of the diameter should be made on air-dry fibers, or if the water-soaked fiber is used proper allowance should be made.

In determining the diameter of wool and hair, it is also to be noticed that few hairs are perfectly round. In order to form an opinion of the sectional form, it is necessary to make a cross-section or observe the

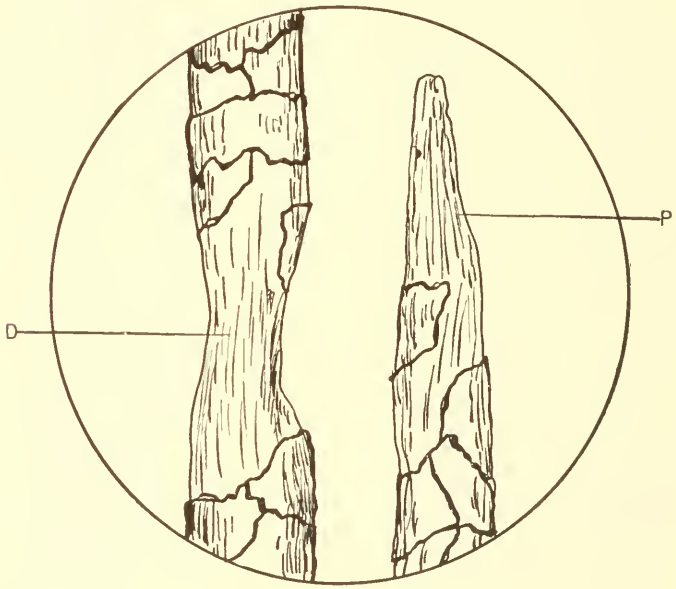


FIG. 51.—Wool Fibers showing Absence of Epidermal Scales. (×500.) *D*, at middle portion of fiber, probably due to disease; *P*, at point of fiber of lamb's wool. (Micrograph by author.)

hair cut in short pieces under the microscope and to turn it on its axis by moving the cover glass. An apparatus has been constructed which stretches out a long hair and turns it on its axis. In this way every diameter of a hair in the dry condition may be determined. A very simple contrivance but one which suffices for the majority of cases, is the following, which was originated by Höhnel. An ordinary slide-glass is taken and glued at each end to a small cork by means of sealing wax, and through these two corks is stuck a thick iron wire which is bent at the outer ends into the form of a sort of crank, so that they may easily be turned on their axes. To the inner ends of the wires, by means of sealing wax, is fastened

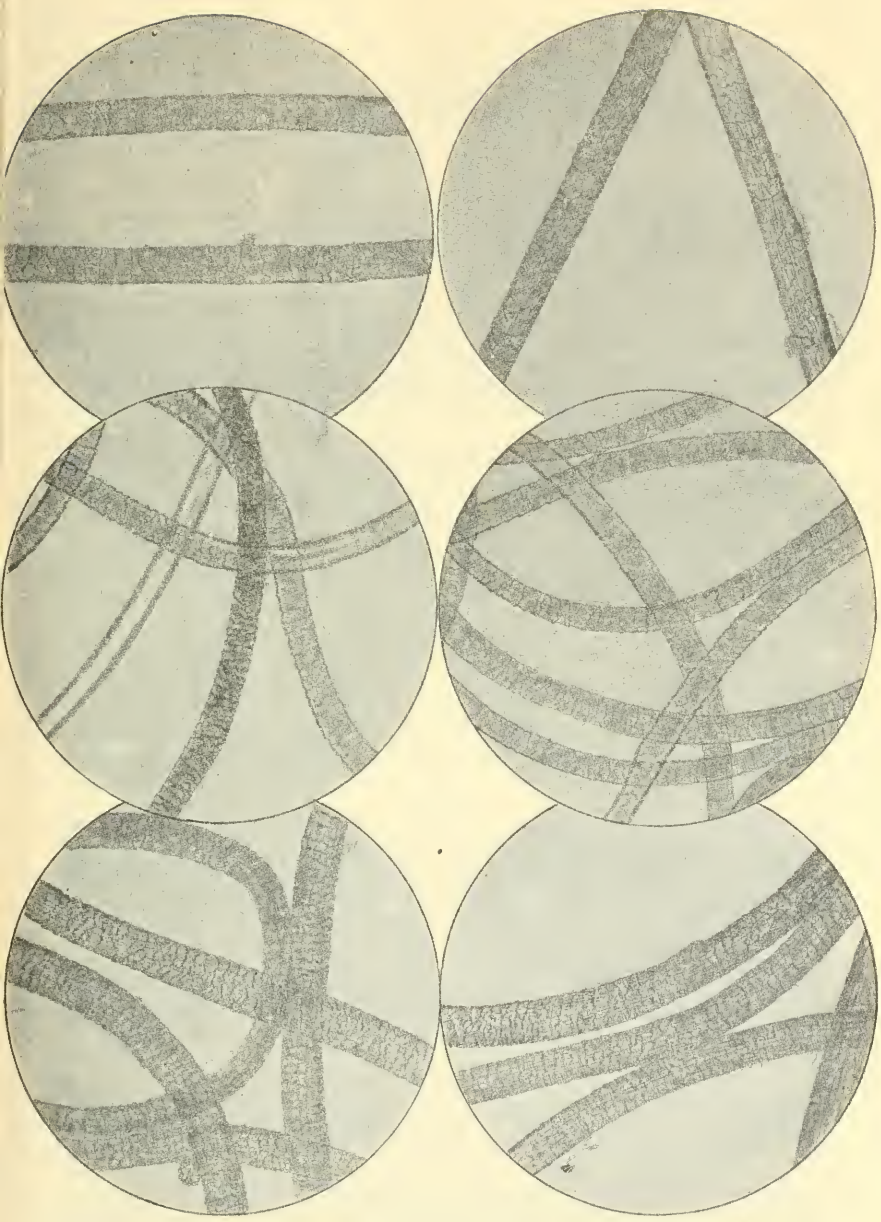


FIG. 52.—American Merino, Treated with Potash and Mounted in Water.

the hair to be examined, so that it may readily be turned on its axis and yet be kept in a stretched condition.

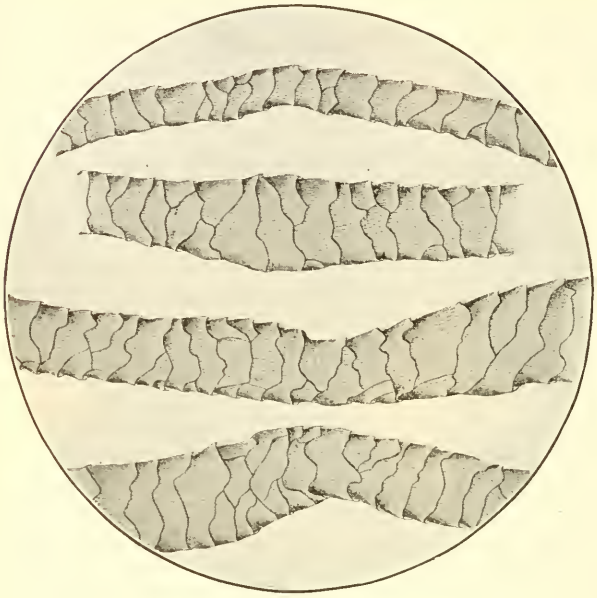


Fig. 53.—Abnormal Wool Fibers showing Variations in Growth.

To make an accurate microscopic examination of stiff beard-hairs, bristles and spines it is necessary to prepare cross-sections. These may rather easily be obtained by stretching the fibers between two pieces of cork and cutting with a razor blade or microtome, or the fibers may be mounted in melted stearin or paraffin and cut after cooling.

When it is desirable to isolate the individual structural elements of a hair from each other, this may be accomplished by treatment with sulfuric acid, ammonia, or

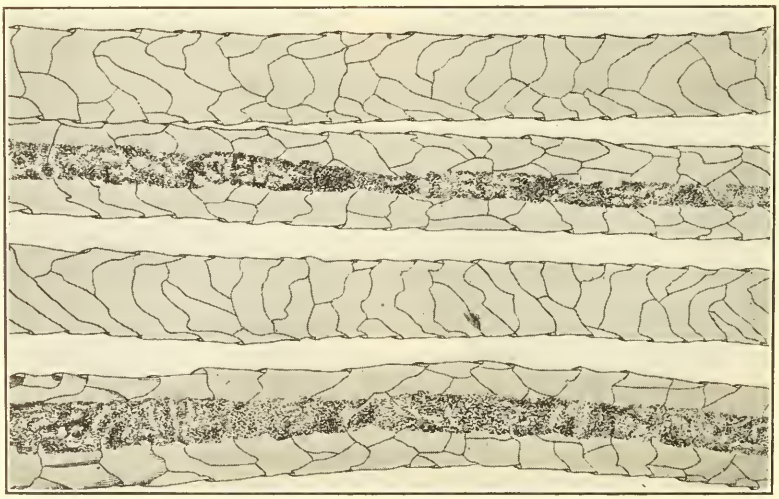


Fig. 54.—Fibers of American Cotswold Wool.

caustic potash. In using sulfuric acid the scales are detached singly or in groups, but they swell up so much that their form cannot be observed very distinctly. With caustic potash the fiber swells up to a great extent, and then it may easily be decomposed into its elements by pressure, these, of course, being more or less changed by the swelling. The most suitable method, according to Nathusius, is to use concentrated ammonia; after two to three minutes' action the epidermal cells are detached without being essentially altered, and they do not curl up, so that their form can be nicely studied. Höhnel has used chromic

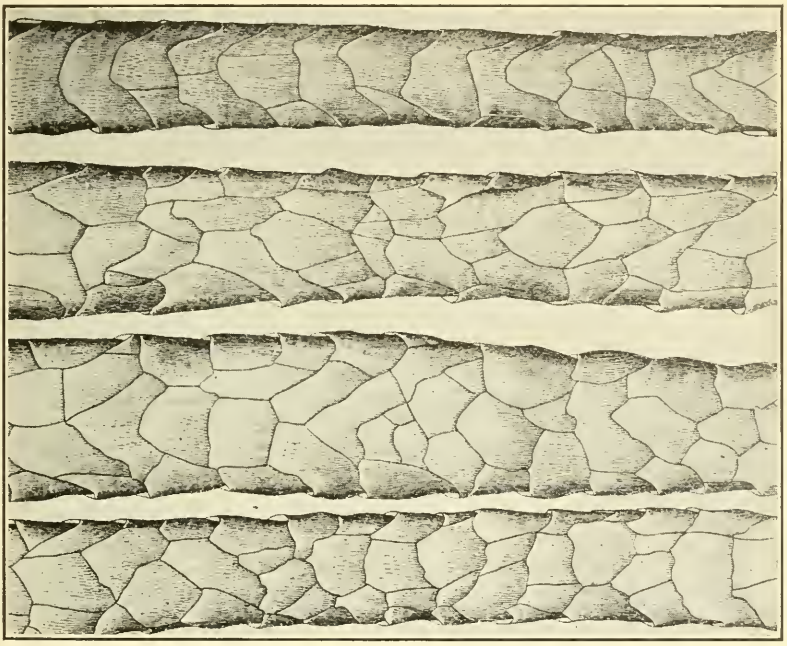


Fig. 55.—Fibers of American Lincoln Wool.

acid with good results; ammoniacal copper-oxide may also be employed advantageously. Nitric acid, which plays an important part in the maceration of plant tissues, cannot be employed for the same purpose on animal fibers; though it should be mentioned that this reagent colors all horn-substance an intense yellow, and therefore is useful. If all forms of fiber are included, according to Höhnel the following may be given as the general microscopical characteristics of sheep's wool: length, 2 to 50 cms.; quite straight to very finely curled and bent; very uniform to very irregular in curl; rough to lustrous; 5 to 100 microns thick; with or without medulla and medullary islands. Marrow, when present, consisting of 1 to 4 rows of cells; marrow cells round or long to linelike, seldom flattened;

always filled with finely granulated matter and air; marrow cells never arranged quite regularly. Marrow cord very narrow or as much as four-fifths the breadth of the fiber; scarcely striated to regularly or irregularly finely to coarsely striated. Epidermis consists of flat to concave scales which may be symmetrical or long shaped or flattened, often semi- or wholly cylindrical. These scales are either arranged platelike side by side or overlap each other like tiles. The projecting edge of the scales is generally appreciably thickened and strongly refractive, usually almost flat, often, however, drawn forward like a saw-tooth, or (seldom) corroded

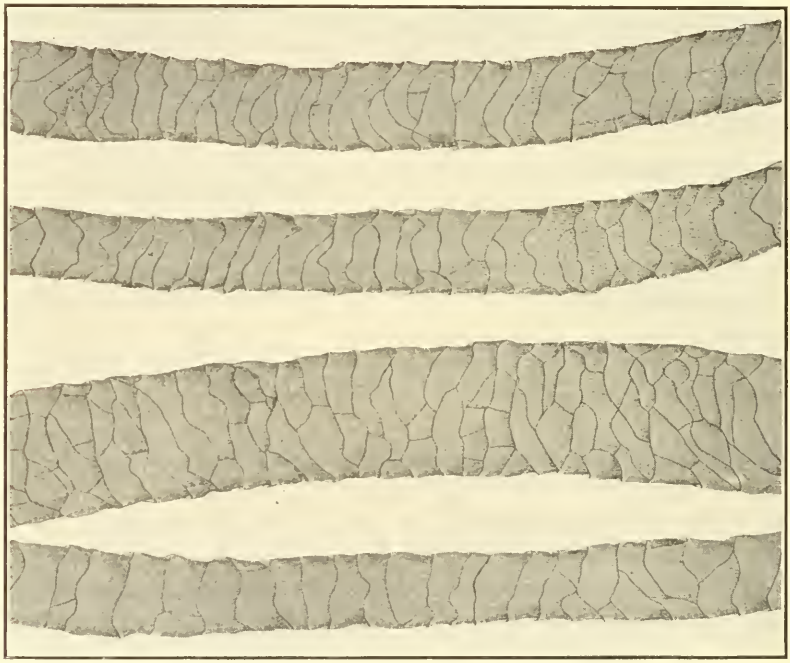


Fig. 56.—Fibers of American Merino Wool.

so as to appear serrated. The natural point of the hair is almost always absent; natural points, as a rule, only occur with any frequency in wool of the first shearing, known as lamb's wool, hence termed lamb's points; they nearly always are covered with overlapping scales which form complete or almost complete cylinders; they have no marrow and are coarsely striated by reason of the fibrous cells. Also, hair follicles or roots are generally absent, since the wool is not pulled out, but sheared off. So-called "pulled wool," which is removed by treatment with milk-of-lime, from hides that are to be tanned subsequently, is the only kind which shows hair-roots; and these are easy to recognise by their slight coloration and egg-shaped form.

4. Microchemical Reactions.—The chemical reactions of the wool fiber under the microscope are not as characteristic as its physical structure. With concentrated hydrochloric or sulfuric acid the fiber gradually dissolves with a red coloration; with nitric acid it dissolves with much difficulty and with a yellow color; ammoniacal copper oxide causes the fiber to distend considerably with gradual disintegration, bringing the scale markings into prominence; solutions of copper or ferric sulfate stain the fiber black.

By sugar and sulfuric acid, animal hair fibers are colored red. Dyestuffs of all kinds (Fuchsine, Aniline Violet, etc.) are readily absorbed; likewise iodine. Boiling concentrated chromic-acid solution dissolves animal fibers immediately; likewise boiling caustic potash. On the other hand, they are not dissolved by boiling hydrochloric acid. Boiling picric acid colors the animal fibers yellow, the coloration being permanent in cold water. Millon's reagent (freshly prepared mercurous nitrate) on boiling colors animal fibers a brick-red. In a mixture of equal parts by volume of sulfuric acid (1.84) and concentrated nitric acid, silk and goat-hair are dissolved in about thirty minutes, while sheep's wool does not dissolve, being merely colored yellow. Since the animal hair fibers all contain sulfur, they yield all the reactions corresponding to that element. With lead acetate solution (mixed with an excess of caustic alkali) a brown or black coloration is produced, due to the formation of lead sulfide. If animal hair fibers are boiled with caustic potash free from sulfur and then diluted with water, the latter solution is colored a fine violet on the addition of sodium nitroprusside.

5. The Epidermal Scales.—The epidermal layer of scales imparts to the wool fiber its characteristic quality of luster. Since the luster of any surface is due to the unbroken reflection of light from that surface, it may be readily understood that the smoother the surface of the fiber, the more lustrous it will appear. When the epidermal scales are irregular and uneven, and have projecting points and roughened edges, the surface of the fiber will naturally not be very smooth and uniform, and consequently will reflect light in only a broken and scattered manner. Such fibers will not have a high degree of luster. On the other hand, when the scales are regular and uniform in their arrangement, and their edges are more or less segmented together to form a continuous surface, the fiber will be smooth and lustrous (Fig. 57). As a rule, the coarser and straighter fibers are the more lustrous, as they approximate more closely to the structure of hair, which has a smooth surface. The luster of the fiber, being dependent on the polished surface of the scales, is influenced largely by any condition which may affect the latter. Treatment with chemical agents, for instance, which will corrode the horny tissue of the scales, will seriously affect the luster, as is evident by allowing alkaline solutions

to act on lustrous wool fibers. High temperatures (and especially dry heat) corrode the epidermal scales and shrivel them up, causing the fiber to lose its luster. In the various mechanical processes through which the wool must pass in the course of its manufacture, the scales of the fiber suffer more or less injury, being torn apart, roughened, and loosened from the surface. In order to minimise the extent of this injury the wool is generally oiled, so that the surface of the fibers may be properly lubricated.

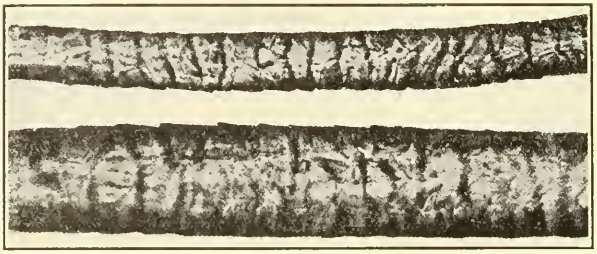


Fig. 57.—Wool from same Fleece, showing Coarse and Fine Fibers and Structure of Epidermal Scales.

Bowman gives the approximate comparative number of scales per inch in different varieties of wool as follows:

Wool.	Scales, per Inch.	Diameter of Fiber, Inch.
East Indian	1000	0.00143
Chinese	1200	0.00133
Lincoln	1400	0.00091
Leicester	1450	0.00077
Southdown	1500	0.00080
Merino	2000	0.00055
Saxony	2200	0.00050

According to the measurements of Hanausek, the size of the epidermal scales on different forms of hair fibers are as follows:

Fiber.	No. of Epidermal Scales per Millimeter Length of Fiber.
Sheep's wool, ordinary	105
" " prime	97
" " merino	114
" " Electoral	100
" " Saxony	121
Angora wool	53
White alpaca	90
Brown alpaca	150
Vicuña wool	100
Camel's wool	90

Hanausek claims that the number of scales on a given length of hair appears to be constant within narrow limits for each kind of hair, and that in the case of wool of certain animals, particularly the merino sheep and Angora goat, the results of counting tests are of considerable value in identification. The scales on Angora wool seem to be the most uniformly distributed.

With respect to the variation in fibers derived from different kinds of sheep, Bowman gives the following classification:

(1) Those sheep the fibers of whose wool most nearly approach to a true hair, the epidermal scales being most horny and attached most firmly to the cortical structure. This class includes all the lustrous varieties of wool, besides alpaca and mohair.

(2) Those where the epidermal scales, though more numerous than in the first class, are less horny in structure and less adherent to the cortical substance of the fiber. This class includes most of the middle-wooled sheep and half-breeds. When two varieties of sheep are crossed in breeding the wool from the resulting offspring is known as "cross-bred." Such wool has a tendency to produce uneven staple unless proper care and selection are exercised in the crossing.

(3) Those where the characteristics of true wool are most highly developed, such as suppleness of fiber and fineness of texture, the epidermal scales being attached to the cortical substance through the smallest part of their length. This class includes all the finest grades of sheep, such as the merino and crosses with it.

The rigidity and pliability of the wool fiber are also largely conditioned by the nature of its epidermal scales. If these fit over one another loosely with considerable length of free edge, the fiber will be very pliable and plastic, soft, and yielding, also easily felted (Fig. 58). Whereas, if the scales fit closely against one another and have little or no freedom of movement, the fibers will be stiff and resistant, and not easily twisted together nor felted.

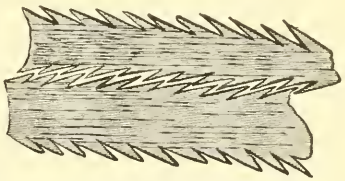


Fig. 58.—Diagram showing Felting Action of Wool by Interlocking of Scales. (Drawing by author.)

6. Felting Quality.—The felting quality of wool is dependent to some extent on the nature of the epidermal scales, as pointed out above. The more the free edge of the scale protrudes from the surface of the fiber, the more easily will the wool felt.

The felting action of wool, however, must not be attributed solely to the interlocking of the scales on the surface of the fiber. This has been the general conception in the past, but the examination of felted fibers does not bear out this idea. If the felting were altogether due to the interlocking of the scales it would require that two fibers be brought together in opposite directions in order to have this interlocking take place. As a matter of fact, in a piece of felted cloth for example, the wool fibers are located in all manner of directions and only a small percentage of them

would be juxtaposed in such a manner as to furnish the necessary conditions for felting by the interlocking of the scales. The felting is largely due, in the first place, to the intermeshing of the fibers themselves by becoming twined round one another, and this condition is especially enhanced by the curl in the fiber. Again, in the felting operation of milling or fulling the surface of the fiber no doubt is softened in such a manner that fibers coming in contact with one another and under the influence of heat, pressure and the chemicals employed, become more or less glued together. As the substance of the scales of the fiber is in reality a form of glue or gelatine, it is easy to understand why this condition can readily be induced by the felting process. Microscopic examination of the intimate structure of felted fibers indicate a strong surface cohesion rather than a mere interlocking of the scales (Figs. 59 and 60). This also explains why it is perfectly possible to felt wool fibers that do not

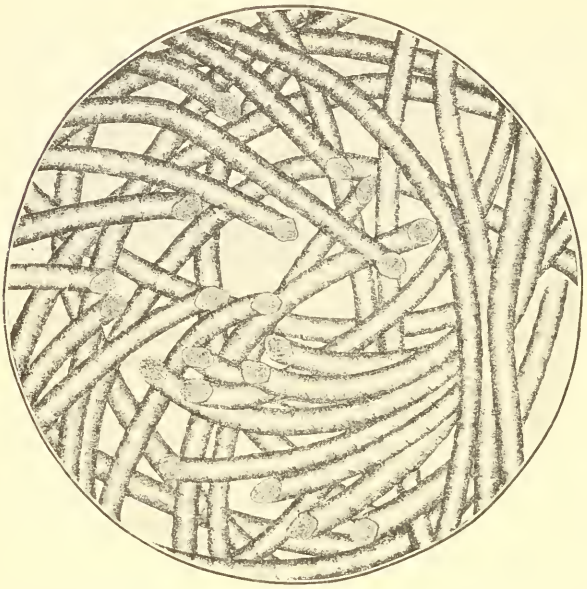


FIG. 59.—Fibers in Unfelted Woolen Cloth.

FIG. 60.—Felted Fibers in Woolen Cloth after Fulling.

exhibit well-defined free scales. Hair, though it has the surface scales, does not have these scales arranged so as to show very much free edge projecting from the surface of the fiber; also these scales are hard and not easily softened to the point where strong cohesion may take place between fibers in contact with one another. If, however, the surface scales are softened so that they become somewhat mucilaginous in character, then by heat and pressure hair fibers may also be felted much in the same manner as ordinary wool fibers. Burgess is of the opinion that the sole cause of felting in wool is the curled nature of the fiber, and that the serrations on the surface have nothing whatever to do with it. He quotes certain Russian wool which has very strongly developed serrations but which is not a good felting wool. Bowman, on the other hand, inclines to the opinion that the serrations or scale projections on the surface of the fiber are the chief cause of the felting. While both of these factors are no doubt causes of felting, the present author is of the opinion that they only partially explain the facts and that the above-mentioned fusing together of the surface of the fibers is the principal cause of felting. Even Bowman, in speaking of the action of water in felting, states that the constituent cells of the fiber become softened by the action of the water and the acid, and seem to be capable of uniting with each other when subjected to rubbing and pressure, until it is difficult, even under the microscope, to distinguish one fiber from another, the whole seeming to form one solid mass. It is not necessary for the fibers to be woven into a cloth, or arranged in a regular manner so as to felt; indeed the reverse is the case, for the less regularity there is in the arrangement of the fibers, the better and more perfect is the felting action.

7. The Cortical Cells.—The cortical layer, or true fibrous portion of the fiber, forms the major constituent of wool. It consists principally of more or less elongated cells, and often presents a distinctly striated appearance, the striations being visible through the translucent layer of scales. The individual cells measure from 0.0014 in. to 0.0025 in. in length, and from 0.00050 in. to 0.00066 in. in diameter, hence are elliptical in form. The cells may be separated from one another by a careful treatment with caustic alkali (Fig. 61). To this cortical tissue the fiber chiefly owes its tensile strength and elasticity.

8. Waviness or Curl.—When the fiber is fine in staple, the cortical cells exhibit more or less unevenness in their growth and arrangement, with the result that the fiber is contracted on one side or the other, giving rise to the waviness or curled appearance of such wools. It is best, perhaps, to speak of the wool being "wavy" rather than "curled," as the latter implies usually a spiral development which involves a twisting of the fiber, and in wool, as a rule, this does not occur. Coarse wools seldom exhibit this wavy structure, or only to a slight degree, the waves being long and

irregular; some fine stapled wools, on the other hand, possess short and very regular waves. This property of the fiber adds much to its spinning qualities, and also to the resiliency of the yarn or fabric into which it is manufactured.

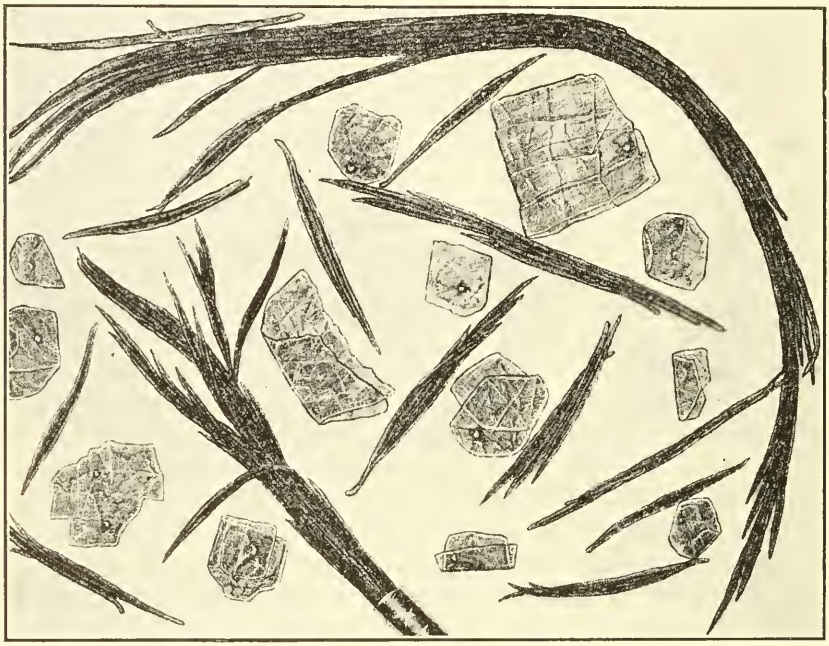


FIG. 61.—Fiber of Wool Decomposed into its Constituent Cells by Alkali, showing Thin, Flat, Plate-like Scales and Long, Narrow Cortical Cells. (Löbner.)

Lafoun gives the following table showing the relation between the diameter of the fiber and the number of curls:

No.	Quality.	Curls or Curves per Inch.	Diameter of Fiber.
1	Super Electa	27 to 29	$\frac{1}{840}$th of an inch
2	Electa	24 to 28	$\frac{1}{735}$th "
3	Prima	20 to 23	$\frac{1}{660}$th "
4	Secunda Prima	19 to 20	$\frac{1}{588}$th "
5	Secunda	16 to 17	$\frac{1}{534}$th "
6	Tertia	14 to 15	$\frac{1}{510}$th "
7	Quarta	12 to 13	$\frac{1}{470}$th "

It will be seen in this table that the finer the wool the greater the tendency to curl; for when the diameter of the fiber is 1/840 in. the number of curves is more than double that which pertains to the fibers whose diameter is 1/470 in.

Wool-hairs exhibit much less development of waves than the true wool

fibers, and the more closely the animal fibers approximate to the structure of ordinary hair, the less pronounced are the waves. Sheep's wool is more wavy than that derived from allied species, such as the various goats, camel, etc. Mohair, for instance, exhibits no wavy structure at all. The exact cause which determines the wavy quality of wool is but ill defined; there appears, however, to be some connection between the waviness, the diameter of the fiber, and the number of scales per inch.

The following table, given by Bowman, shows the relation between the number of waves and the diameter of the fiber.

Wool.	Waves per Inch.	Diameter of Fiber, Inch.
English merino	24 to 30	0.00064
Southdown	13 to 18	0.00078
"	11 to 16	0.00100
Irish	7 to 11	0.00120
Lincoln	3 to 5	0.00154
Northumberland	2 to 4	0.00172

The fineness of the wool fiber appears to bear a definite relation to its waviness, and attempts, therefore, have been made in Europe to grade the fiber according to the number of waves in one centimeter, as follows: Super electa, over 11; electa, 9–10; prime, 7–9; second quality, 6–7; third quality, 5–6; fourth quality, 4–5. The different kinds of waves, known as normal bent, close bent, high bent, flat bent, and long bent, also appear to be due to differences in the fineness, although but little is known on this point as yet.

Bohm (*Schafzucht*, vol. I, p. 182) gives the following table for the number of waves or crimps in various kinds of wool:

Grade.	Number of Crimps per Inch.	Measurements of Fineness.		
		In Centimillimeters.	In Thousandths of an Inch.	In Fractions of an Inch.
Super Electa plus plus	32	1.25 to 1.50	0.4921 to 0.5905	$\frac{1}{2031}$ to $\frac{1}{1693}$
Super Electa plus	30 to 32	1.50 to 1.60	0.5905 to 0.6496	$\frac{1}{1693}$ to $\frac{1}{1587}$
Super Electa	28 to 30	1.65 to 1.775	0.6496 to 0.6988	$\frac{1}{1587}$ to $\frac{1}{1430}$
Prima Electa	26 to 28	1.775 to 1.90	0.6988 to 0.7480	$\frac{1}{1430}$ to $\frac{1}{1336}$
Secunda Electa	24 to 26	1.90 to 2.03	0.7480 to 0.7885	$\frac{1}{1336}$ to $\frac{1}{1267}$
Hohe Prima	23 to 24	2.03 to 2.225	0.7885 to 0.8759	$\frac{1}{1267}$ to $\frac{1}{1141}$
Prima	21 to 23	2.225 to 2.40	0.8759 to 0.9448	$\frac{1}{1141}$ to $\frac{1}{1058}$
Geringe Prima	20 to 21	2.40 to 2.54	0.9448 to 0.9999	$\frac{1}{1058}$ to $\frac{1}{999}$
Hohe Secunda	19 to 20	2.54 to 2.666	0.9999 to 1.0496	$\frac{1}{999}$ to $\frac{1}{952}$
Secunda	17 to 19	2.666 to 2.90	1.0496 to 1.1417	$\frac{1}{952}$ to $\frac{1}{875}$
Geringe Secunda	16 to 17	2.90 to 3.175	1.1417 to 1.2499	$\frac{1}{875}$ to $\frac{1}{799}$
Tertia	13 to 16	3.175 to 3.70	1.2499 to 1.4566	$\frac{1}{799}$ to $\frac{1}{686}$
Quarta	0 to 13	3.70	1.4566	$\frac{1}{686}$

The waviness of the wool fiber may be temporarily removed by wetting with hot water and drying while in the stretched condition.

9. The Medullary Cells.—The medulla, or marrow, of the wool fiber consists of round or slightly flattened cells, usually somewhat larger in section than those comprising the cortical layer. The size of the medulla varies considerably in different varieties and grades of wool, and even shows large variations in fibers from the same fleece. At times it may occupy as much as one-quarter to one-third of the entire diameter of the fiber; and again, it may be reduced to almost a line, or even disappear completely (Fig. 62). Wool-hairs exhibit the presence of a distinct medulla more frequently than the true wool fibers. The latter mostly show scarcely any inner structure at all, though at times there may be noticed isolated medullary markings, but usually the fiber is so transparent that it presents no markings at all. In camel-hair, however, the medullary portion shows up very distinctly, in some fibers appearing as a continuous dark band occurring about three-fourths of the width of the fiber, while in other fibers it shows a well-defined granular structure. In hairs of some other animals the medullary part exhibits a structure which is distinctly characteristic of the fiber; in the hair of the cat (Fig. 40, No. 3), for instance, the medullary cells appear in a reticulated form, and in the hair of the rabbit (Fig. 40, No. 1) they occur as a series of laminæ very regularly superposed on each other.

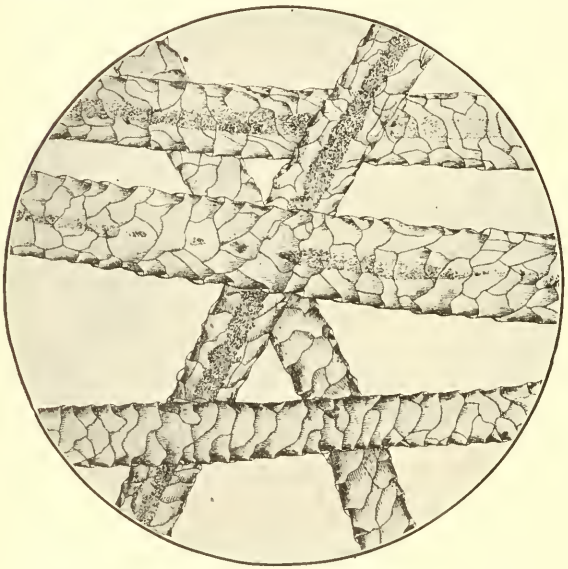


Fig. 62.—Wool Fibers showing Pigmented Medulla.

The medulla may consist of a single series of cells, or of several series arranged side by side; sometimes these cells occur in a discontinuous and rather irregular manner, the intervening spaces of the medulla being filled with air which is especially true of cow-hair. The walls of the medullary cells are generally very thin and indistinct, and the contents consist of finely granular masses, air, and, in the case of colored hairs, of pigment granules.

The medulla, as a rule, is more developed in beard-hairs than in wool-hairs, and more in coarse grades of wool than in the finer qualities. There also appears to be more or less relation between the breed of the wool and the morphological characteristics of the medullary cells, although this is a subject which as yet has been but little studied. At times the medullary cells exhibit but little difference from those of the cortical layer, and these two portions of the fiber become continuous in their appearance; that is to say, no line of demarcation can be drawn between the medulla and the surrounding cortical layer.

Usually the medulla consists of a continuous axial cylinder of cells, though at times the continuity may be interrupted, resulting in isolated cells or groups of cells, forming the so-called "medullary islands." The function of the medulla is to provide the living fiber with an inner canal for the flow of juices whereby it receives nourishment for its growth. It also adds much to the porosity of the fiber, forming a capillary tube whereby the latter may absorb solutions of various kinds, such as dye-stuffs, different salts, etc., allowing these to gradually permeate through the cortical layer as well. The epidermal layer of scales is rather impervious to the transpiration of solutions, and only permits of their entrance into the fiber at the joints of the scales, so it may be seen that the medulla of the fiber becomes an important adjunct in the chemical treatment of wool in the processes of mordanting, dyeing, and bleaching. It might also be noted, in this connection, that the epidermal scales become but slightly, if at all, dyed when various coloring matters are applied to the fiber, but remain colorless and translucent. Hence it may be readily understood that if two samples of wool are dyed simultaneously, the one consisting of fibers having small and open scales, while the other has a thick and highly resistant epidermis, the resulting color on the two samples will have a different quality or tone, due to the influence on the latter of the uncolored and translucent scales. In wools where this influence is very marked it is almost impossible to obtain rich and full shades of color, due to the transparency and luster of the surface, which allows of considerable white light being refracted through the fiber along with the reflected color. This also explains the well-known fact that the longitudinal surface of the fiber in many cases presents a different tone of color than the cut ends, the latter usually being richer and deeper in tone; as may be noticed in cut-pile fabrics, such as occur in rugs, plushes, etc.

In some cases the epidermal layer, instead of being highly translucent, is opaque and white; this is true of many varieties of coarse wool-hairs, and such fibers as cow-hair, etc. In such instances the dyed fiber will lack liveliness of tone and appear rather dead and flat.

10. Pigmentation or Color.—The medullary cells frequently contain pigment matter, either continuously or in isolated cells; and this may

occur even in fibers usually classified as white wool. According to Bowman (*Structure of the Wool Fiber*, p. 267) the pigment occurring in sheep's wool has the following composition:

	Percent
Carbon	55.40
Hydrogen	4.25
Nitrogen	8.50
Oxygen	31.85

Sometimes the pigment permeates not only the medulla, but also the cells of the cortical layer, in which case the fiber as a whole appears colored. To this class belong the variously colored wools, ranging from a light brown to almost a black. The hair of camels, goats, and other animals is also more or less colored, and to a much more general extent than sheep's wool.

The natural coloring matter is contained particularly in the fibrous and marrow cells in a granular form. In the marrow cells these granules are generally crowded together, whereas in the fibrous layer they are in long rows (Höhnel). Slightly colored fibers show the walls as almost colorless. On the other hand, heavily colored fibers have the walls of the cells also impregnated with coloring matter, while in artificially dyed wools the dyestuff is always seen in the walls, these being uniformly colored. In the case of artificially dyed wools, therefore, the lumen disappears; whereas with naturally colored wools and hairs this is generally distinct through the coloring matter. Consequently naturally colored wools, by reason of the parallel arrangement of the granules of coloring matter, appear distinctly striated, which is never the case with artificially dyed fibers.

According to McMurtrie (*Examination of Wools*) the idea advanced by some German authorities that the presence of the pigment canal in the fibers has a serious effect upon their strength is not true. McMurtrie states: "We find it almost peculiar to the Cotswold breed, so far as our examinations have extended, though Bohm and others say it belongs to all animals covered with fibers tending to the hairy type. We have seen only traces of it in the Lincoln wool, however, and none whatever in the wool of the pure Merinos and Downs. In the Oxforddown wools it is naturally present, and is another evidence of the origin of the breed. It is not always confined to a single column or canal, nor does it always extend throughout the entire length of the fiber containing it, for it frequently occurs in detached masses in the center of the fiber, or distributed through nearly the whole of the fibro-cellular tissue. This refers only to the white pigment, which alone we have had an opportunity to study. The colored, black, or brown pigments are not so confined, and differ in

character, being distributed through the entire mass of the fibro-cellular tissue. Since it seems to affect neither the strength nor the elasticity of the fiber, so far as we have been able to determine, the principal interest it may have will depend upon the fact that it is peculiar to the long-wool breeds, principally the Cotswold, and entirely wanting in pure Merinos. Taken in connection with the diameter of the fiber and the forms of the scales, it must assist in the determination of the purity of the blood of the animal under consideration. If a fiber containing the pigment canal be treated with a strong solution of potassium or sodium hydroxide, and with the aid of heat it gradually disintegrates, the fibro-cellular tissue is completely broken down and many of the cells dissolved, while the cells constituting the pigment column or canal remain intact. By longer action of the solvent they are separated from each other, and upon agitation caused by pressure upon the cover glass they separate and become distributed independent of each other through the surrounding mass. We then find them to consist of irregular masses, in many cases angular, in some cases rounded, and generally lined or filled with granular matter of which, as already stated, the true nature has never been determined."

FIG. 63.—Pigment Canal in Cotswold Wool Fiber. Prepared by Treating with Ammonia, then Sulfuric Acid and Mounting in Water.

11. Kempy Wool.—Frequently, through disease or other natural causes, the medulla of the wool fiber is imperfectly developed (Fig. 64), or the scales of the epidermis are cemented together, in consequence of which the wool will not absorb solutions readily, and hence will not be dyed (or mordanted) at all, or only slightly. These fibers, which are known as kemps, will occur through the mass of the wool as undyed streaks, and will give the yarn or fabric a speckled appearance. Kempy wool is said to be due to undue exposure of the sheep and to bad feed-

ing. It is also more noticeable in wools grown in mountainous regions. Kempy wool should not be used in fabrics intended to be dyed a solid color. For blankets, Scotch tweeds, horse-rugs, mantle cloths, and the like, the occurrence of kempy fibers in the wool is not an especial drawback. Not only may this condition, however, be brought about by natural causes, but it may at times be the result of improper manipulation during manufacturing processes. According to Bowman, kemps have a dense appearance, the cellular character being entirely obliterated, the fiber assuming the appearance of an ivory rod without any internal structure being visible.

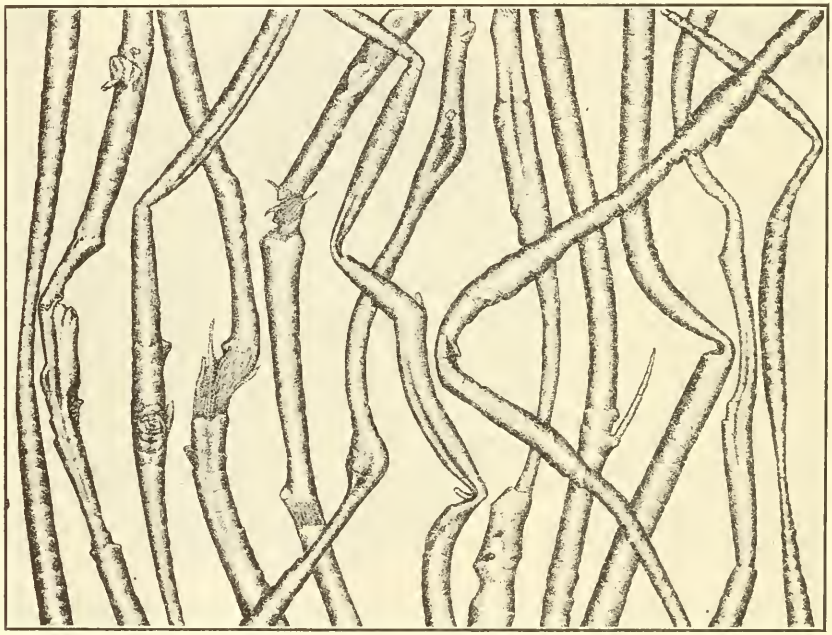


Fig. 64.—Kempy Wool Fibers.

Kempy fibers are always much thicker than the rest of the wool among which they grow, and the medulla or central portion of the kemp is quite thick.

12. Pulled Wool.—There is a certain class of wool known in trade as pulled wool, also known as *tanners'* wool and *glovers'* wool. This is obtained from the pelts of slaughtered sheep, and is usually removed from the skin by the action of lime, the fibers being pulled out by the roots. In the process, the medulla becomes stopped up with solid insoluble particles of lime, which is also true of the end pores of the cortical layer and the joints of the scales. As a consequence, the fiber is very difficult to impregnate with solutions, and will remain more or less completely undyed. This

non-porous character is also enhanced, perhaps, by th
fiber does not possess a freshly cut end, but still retains th
is more or less rounded off and closed by the coagulation a
of the juices in the hair follicle.

Pulled wool is also known as *skin wool* or *slipe wool*. Be
lime method of treating pulled wool, there is also the so-called s
process, which has the advantage of not injuring the fiber as mu
the lime method. The best method, however, is the sodium sulfide pro
of treatment, as this leaves the fiber in a rather good condition. Pull
wool is largely employed for blending with fleece wool or shoddy.

13. Physical Properties.—In its physical properties, the wool fiber varies within large limits, depending on the breed and quality of the

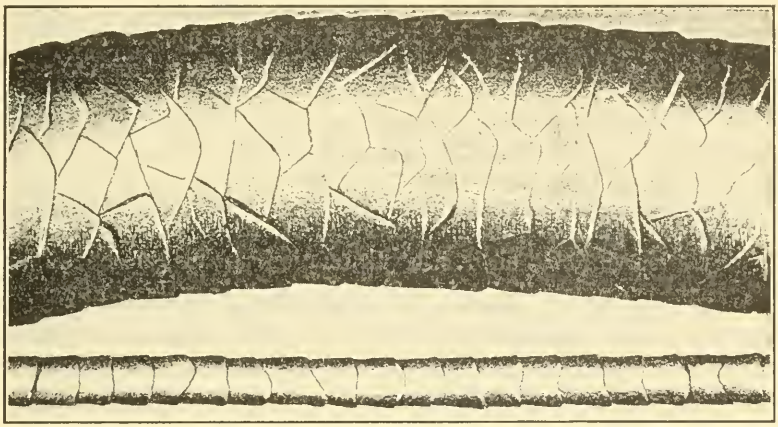


FIG. 65.—Showing Extreme Variations in Diameter of Wool Fibers. (×550).

sheep, and also the diameter of the fiber and the part of the fleece from which it was derived. The strength of wool, and of animal hairs in general, is due to the peculiar structure of the fiber. In the first place, the external sheath of horny tissue of flattened cells which take the form of scales, offers considerable resistance to crushing strains, and are also locked rather firmly together in the direction of the length of the fiber; this has a tendency to resist any diminution in the diameter of the fiber which would be felt when the latter is stretched. Then, too, the internal cortical cells of the fiber are so arranged as to present a very firm structure, being firmly interlaced together, consequently they offer considerable resistance to rupture. It has been noticed by a microscopical examination of a broken fiber that the cells themselves are never ruptured, but only pulled apart from one another; this is evidence that the cell-wall is of a strong texture. The latter is probably formed of a continuous tissue

which is less than 0.0002 in. in thickness, as under the highest powers of the microscope it exhibits no evidence of structural elements.

14. Strength and Elasticity.—Bowman gives the following table, which records the average results of a number of experiments on the strength and elasticity of the wool fiber:

Wool.	Tensile Strength, Grams.	Elasticity, Percent.	Diameter, Inch.
Human hair	106.0	36.6	0.00332
Lincoln wool	33.0	28.4	0.00181
Leicester	31.0	27.3	0.00164
Northumberland	28.0	27.0	0.00149
Southdown wool	5.9	26.8	0.00099
Australian merino	3.2	33.5	0.00052
Saxony merino	2.5	27.5	0.00034
Mohair	38.0	29.9	0.00170
Alpaca	9.7	24.2	0.00053

It is interesting to compare these figures of tensile strength for equal cross-sections of fiber. As the cross-section varies with the square of the diameter, by taking the ratio of the latter numbers and multiplying by the tensile strength, a figure is obtained which represents the tensile strength for equal diameters of fibers. In this manner the following table has been calculated, taking human hair as the standard for comparison, as it has the largest diameter:

Human hair	100.0
Lincoln wool	96.4
Leicester	119.9
Northumberland	130.9
Southdown wool	62.3
Australian merino	122.8
Saxony merino	224.6
Mohair	136.5
Alpaca	358.5
Cotton (Egyptian)	201.8

It will be noticed from this table that Saxony merino wool is by far the strongest of the different grades of wool. It is also interesting to note that cotton is considerably stronger than the majority of wools.

Barker[1] has given the comparative strength of equivalent yarns of worsted and other fibers, as follows:

[1] *Jour. Soc. Dyers & Col.*, 1905, p. 36.

Yarn.	Breaking Strain, Ounces.	
	1 Inch Test.	27 Inches Test.
Tram silk (4)	45.0	40.0
Ramie (12)	34.5	24.5
Linen (15)	29.5	18.0
American cotton (14)	17.0	13.5
Viscose silk (2)	11.0	11.0
Luster worsted (9)	9.0	5.0
Botany worsted (9)	7.5	3.5

The size of the yarn in each case is equivalent to 1/30's worsted. The numbers after the name of each yarn represent the turns per inch, being the respective normal amount of twist in each case. The figures in the first column represent more nearly, probably, the actual breaking strain; and those in the second column represent rather the slipping strain of the yarn, and approximate more closely to the true weaving strength.

McMurtrie gives the following table of results, representing an average of a large number of tests on the tensile strength of various wool fibers:

	Strain in Grams.		
	Highest.	Lowest.	Average.
Cotswold	44.54	16.10	30.44
Leicester	30.00	15.50	23.70
Lincoln	36.72	15.79	25.66
Southdown	21.29	6.48	12.78
Oxford	45.15	19.15	30.43
Merino	11.92	3.86	7.35

The following table is also given showing the relative resistance and stretch of wool fibers, representing a mean of a very large number of individual tests:

Permanent Stretch in Millimeters.	0.25.	0.50.	1.00.	1.50.	2.00.	2.50.	3.00.	3.50.	4.00.	4.50.	5.00.
Resistance in lbs. per sq. in.	21.720	22.659	24.527	25.805	26.677	27.911	29.416	32.439	35.065	36.524	41.300
Total stretch in mm.	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00		
Resistance in lbs. per sq. in.	21.233	24.018	25.465	26.723	38.285	31.024	34.736	34.804	43.157		

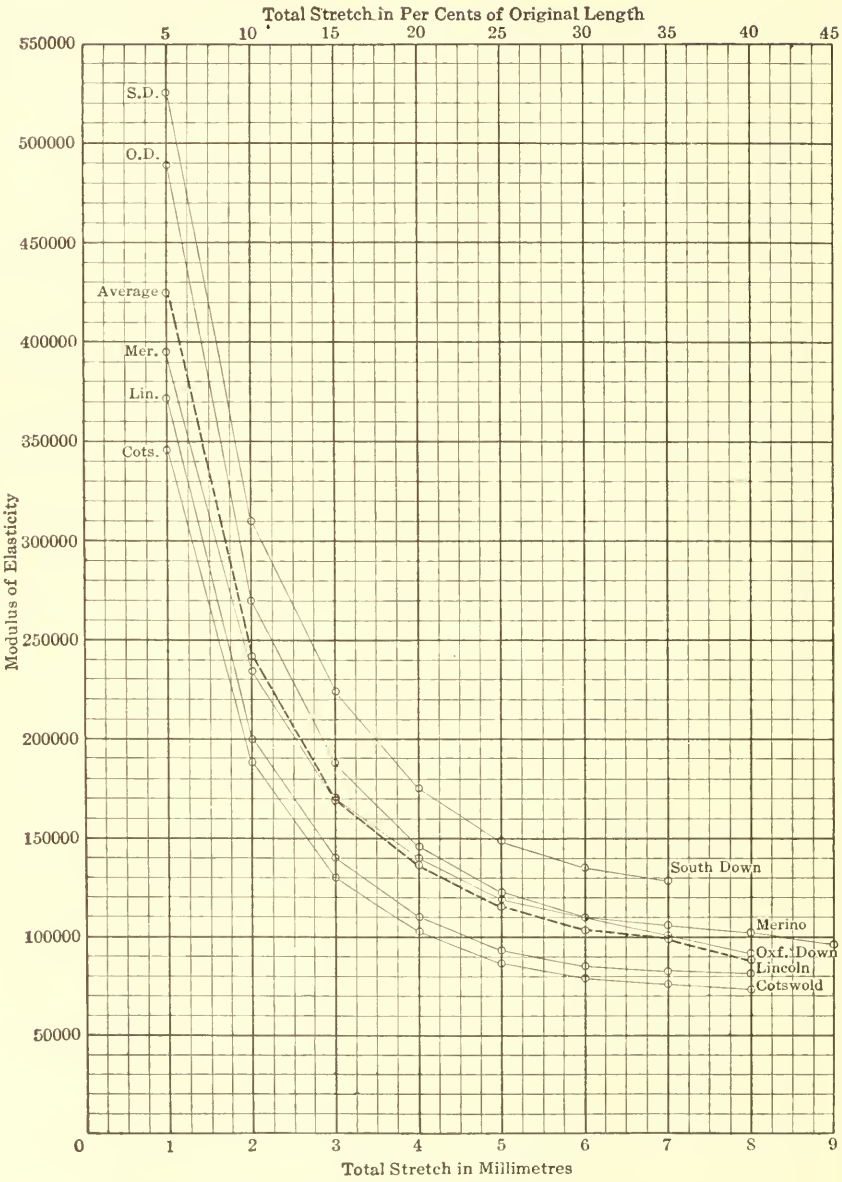


FIG. 66.—Comparative Moduli of Elasticity of Different Wools.

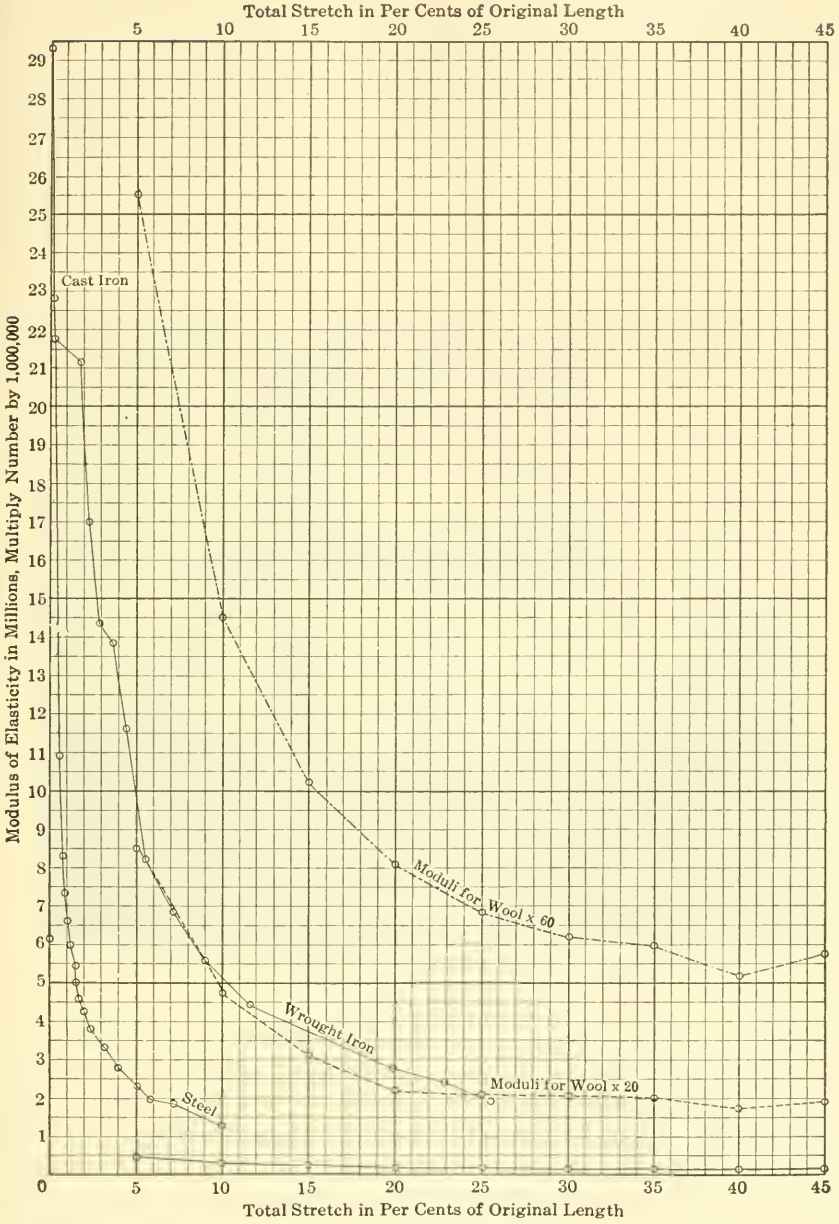


FIG. 67.—Comparative Moduli of Wool, Iron and Steel.

McMurtrie gives the preceding diagrams (see Figs. 66 and 67) showing the comparative moduli of elasticity of various kinds of wool fibers, also showing the comparison of wool fibers with iron and steel.

15. Length and Fineness of Staple.—In length, the wool fiber varies between large limits, not only in different sheep, but also in the same fleece. Generally speaking, the length may be taken as being between 1 and 8 ins. The diameter of the fiber is also very variable, even in the same fleece, but may be taken as averaging from 0.0018 to 0.004 in. According to Höhnel, the diameter of sheep's wool varies from 10 to

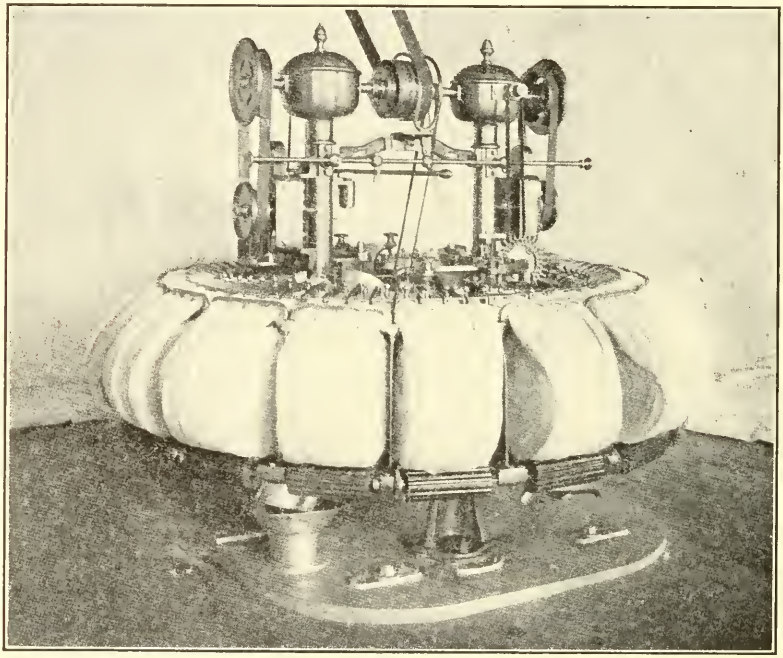


Fig. 68.—Wool Combing Machine for Preparing Tops. (Noble.)

100 microns and according to Cramer, the thickness of the hairs from one and the same fleece may vary from 12 to 85 microns. According to Barker, the finest wool has a diameter of 1/2000 to 1/3000 in. while coarse Algerian wools may rise to maximum diameter of 1/275 in. Difference in fiber diameter of wool forms an important source of the varied and composite results realised in woven manufactures. For certain descriptions of cloth, such as face-finished textures, botany worsteds and cashmeres, wools having a fine diameter are selected; for tweeds, wools of a coarser fiber are used; and for luster goods, wools of a regular external structure, and of a small or medium diameter, are required, according

to the quality of the fabric intended. Between the finest grown wools with an average diameter of 1/2400 in. and the thick-haired wools with an average diameter of 1/500 in., there are numerous and complex gradations in fiber diameter (see Fig. 65).

According to their length of staple, wool fibers are graded into two classes: tops and noils.[1] The former includes the longer stapled fibers, which are combed and spun into worsted yarns, to be manufactured into trouserings, dress-goods, and such fabrics as are not fulled to any extent in the finishing. The latter class consists of the short-stapled fibers, which are carded and spun into woolen yarns to be used for weft and all classes of goods which are fulled more or less in the finishing operations, where a felting together of the fibers is desired. On comparing worsted and woolen yarns, it will be noticed that the former are fairly even in diameter and the individual fibers lie more or less parallel to each other, whereas in woolen yarns the diameter is very uneven, and the fibers lie in all manner of directions.

In the distinction between woolen and worsted yarns and fabrics, it is interesting to note that even in remote times the Romans had two distinct types of fabrics, known respectively as "trita" and "densa"; the former being a thin, flimsy cloth made from long-fibered wools and spun into fine threads, and consequently resembling the worsteds of to-day; the latter fabric corresponded to our woolen goods, being a closely woven felted fabric spun from shorter and coarser wools. The object in worsted manufacture is to keep the fibers in the yarns as straight and as parallel as possible, and free from lumps and irregularities, consequently the wools employed have to be thoroughly classified and sorted. Worsted yarns are also spun to much finer counts than woolen yarns, and consequently worsted fabrics are usually of lighter weight than wool goods. Woolen

[1] Noils consist of the short fiber removed from wool during the operation of combing. Naturally there are many classes of noils, depending on the character of the wool used. In length noils vary from about 2 ins. (hair noils) to under ½ in. (botany noils). As noils are short they are suitable only for woolen yarns and felting purposes; they will also contain the other impurities combed out, which consist mostly of vegetable matter; consequently mostly noils have to be carbonised before carding. Cape noil is probably the most valuable on account of its fine white color; it is used in making woolen fabrics, shawls, blankets and hats. Botany noil is also valuable, and though short is fine in fiber and quite white; it also possesses good milling properties. Cross-bred noils are of lower quality; the fiber is longer, smoother and stiffer and is not so satisfactory for spinning. The luster is generally good, but the color is yellowish and the milling properties poor. The best qualities of noils are used in hats and blankets while the lower grades are blended with mungo and shoddy for low-grade woolen. They are also used in the making of carpet yarns where their luster is valued. Mohair noils are very lustrous and soft and silky, but have poor felting properties and are difficult to spin. They are used in cheap woolens and carpet yarns, and certain grades are used for stuffing mattresses and the like.

dress-goods, for example, seldom run below 10 ozs. per yd. (54 in. width), while worsted fabrics may run as low as 4 ozs. per yd. for the same width. On the other hand, worsted fabrics are seldom made of over 24 ozs. per yd. weight, while woolen goods (such as overcoatings) may weigh as high as 40 ozs. per yd.

16. Testing Wool Tops.—E. W. Tetley (*Textile Manufacturer*) gives the following method of testing wool tops for quality of fiber. A practiced eye can very accurately distinguish the different qualities. The best

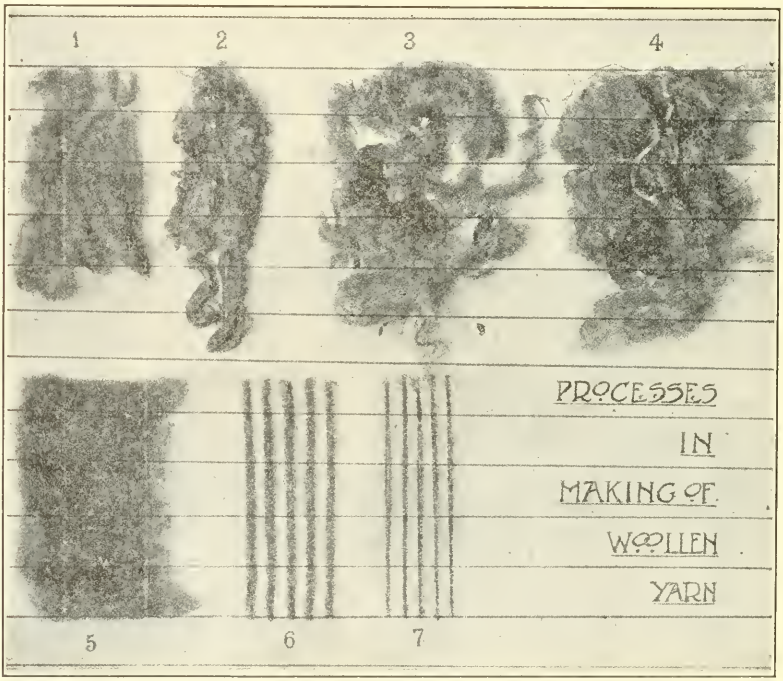


FIG. 69.—Illustrating Woolen Yarn Manufacture: (1) Greasy cross-bred; (2) Scoured and dyed; (3) Wool blend; (4) Passed through Fearnought machine; (5) Scribbled; (6) Carded slubbing; (7) Mule spun yarn. (Tetley.)

thing to do, however, is to procure a standard range of tops of guaranteed quality, from a first-class comber, and use them as a fixed standard against which any new qualities may be tested. To make a good spin, it is imperative that a top should possess uniformity in length of fibers. A simple method of ascertaining the proportion of long, medium, and short fibers in a top is as follows:

The top is taken between the finger and thumb of the right hand, and the base of the left hand placed firmly on the sliver, at just such a distance away that by pulling the "top" with the right hand the fibers

separate, and a " draw " is thus made. The fringe will then be of the longest fibers. A black board or cloth is required. The base of the left hand is then placed on the fringe of the " draw," and the same operation repeated, thus making a " draw " of the longest fibers. This is further repeated, the lengths of the " draws " becoming shorter and shorter, until the original " draw " is finished, when the different lengths of the fibers in the top will be ranged side by side on the black ground, and the proportion of each, as well as the thickness, can be readily seen (Fig. 70).

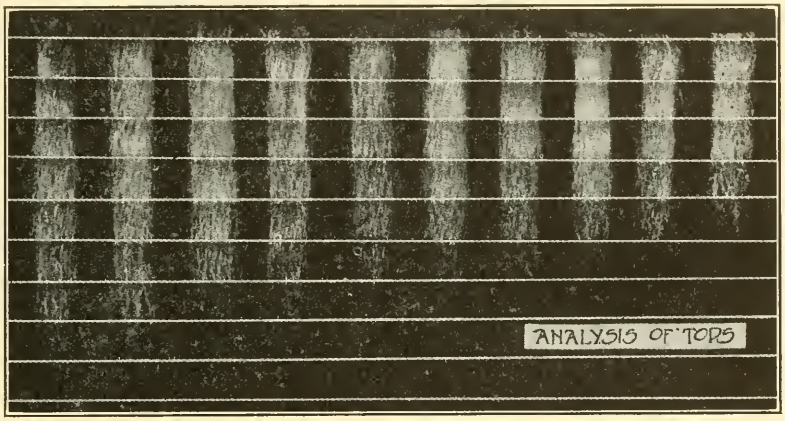


Fig. 70.—Illustrating Analysis of Tops for Uniformity and Quality. Cross-lines = 1 in. apart; Longest = 7 to 8 ins.; Shortest = 4 ins.; Bulk = 6½ ins.; Approximate percentage is 8 ins. = 20%; 7 ins. = 30%; 6 ins. = 20%; 5½ ins. = 10%; 5 ins. = 10%; 4 ins. = 10%. (Tetley.)

17. Blending of Wool in Manufacturing.—The blending of different grades and varieties of wool is an operation requiring great skill and judgment. It requires a thorough knowledge of how the fibers will combine with each other, and the cost must be adjusted to a prescribed amount with a very small margin for error. The mixture may consist of mohair, camel-hair, shoddy, mungo, extract, and noils of all descriptions, as well as cotton and silk waste, but the whole must be so blended that no particular fiber stands out prominently, or the result will be unsatisfactory. The length of the staple is an all-important item, since it affects the conditions of mixing proportions very much more than the weight, and will in itself completely change the character and appearance of yarn or cloth made from it. Short wools are best adapted for blending, as mixtures either of different colors or of qualities. Those of long staple are difficult to mix with short fibers, and tend to appear on the surface of the cloth when manufactured, besides requiring to be broken up in the carding. Imperfect blends result in streaky yarns. The streakiness may not be

RANGE OF TOP QUALITIES

No.	Quality of Staple.	Length.			Diameter.		Strength, etc.	Color and Luster.	Handle.	Uniformity.	Curliness. Approximate Waves per Inch.	Counts of Yarn, Limit.
		Longest. Ins.	Shortest. Ins.	Bulk. Ins.	Inch, Decimals.	Inch, Fractions.						
1	28's	13	6	9	0.0028	1/367	Weak (kempy)	Yellow, no luster	Harsh (very)	Irregular	None	16's
2	32's	13	7½	10	0.0020	1/500	Rather weak	Yellowish, fair luster	Rather harsh	"	"	24's
3	36's P.	12	8	10	0.00163	1/613	Fairly strong	Yellowish, good luster	Fairly soft	Fairly uniform	"	28's
4	40's P.	11½	7½	10	0.00147	1/680	Strong	Yellowish, very lustrous	Soft	Uniform	Slight	36's
5	44's P.	11	7½	10	0.00136	1/735	Very strong	Yellowish, very lustrous	"	Very uniform	"	40's
6	46's P.	10	5½	8	0.00128	1/781	Strong	Yellowish, good luster	Rather harsh	Uniform	"	42's
7	46's C.	9	4	7	0.00128	1/781	Sound	Fairly white, fair luster	"	"	5 waves	40's
8	50's	8	4	6½	0.00121	1/826	"	Fairly white, fair luster	"	Fairly uniform	10 "	46's
9	56's	6½	3½	5	0.00106	1/943	"	Fairly white	Fairly soft	"	15 "	48's
10	58's	6	3	4½	0.00095	1/1053	"	Good white	"	"	20 "	50's
11	60's Super.	5½	3	4½	0.00089	1/1124	"	"	Soft	Uniform	25 "	50's
12	64's	5	2½	4	0.00079	1/1266	"	"	"	"	30 "	56's
13	70's	4½	2½	3½	0.00073	1/1370	"	Very white	Very soft	"	34 "	60's/80's
14	80's	4	2½	3½	0.00067	1/1493	Very sound	"	Extra soft	Very uniform	38 "	100's
15	90's	4	3	3½	0.00060	1/1677	"	Extra white	"	Extra uniform	40 "	120's/150's

visible to the eye if the colors are the same, but it will show in the manufactured article. The nearer the fibers approach each other in length of staple the simpler is the blending.

The theory of blending can never be put down in formula, or conducted on hard and fast lines, since the materials vary so much that nothing but long experience can be trusted, while a small difference in cost may make all the difference between a profit and a loss. The various bodies used for making blends may be briefly described as follows: Shoddy is wool recovered from fairly long-stapled material, which has not been milled. Mungo is the recovered fiber from cloths which have been heavily milled or felted; on this account mungo is ill adapted for working up into yarn alone, and is usually mixed with something with a longer staple, or with cotton, and is commonly made up into low counts of weft yarns. Having once been through the felting process, mungo fibers have lost much of their felting capacity owing to their surface scales being more or less damaged by disintegration, and as mungo is a very short fiber it requires careful judgment on the part of the blender to know what class of material will best go along with it. For making cloths with a fine, dense, mossy nap, mungo answers extremely well, but requires some binding material along with it to compensate for its shortness of fiber. Extract wool is that produced from rags which have contained cotton or vegetable matter which has been removed by carbonising with acid before the rags were pulled.

The best cotton for a woolen blend is the rough Peruvian, which strongly resembles wool in being long, rough and curly. It goes frequently by the name of vegetable wool, and might easily deceive anyone but an expert. In the manufacture of merino yarns it is extensively used and in addition to lessening the cost of manufacture it confers strength and luster, besides reducing the tendency of the wool to shrink.

Wool noils are the short fibers separated during the process of combing, and these, being pure new wool, form the best and most expensive materials in a woolen blend. Camel-hair noils are the short fibers from camel's hair. The hair consists of fine yellowish brown, curly fibers, mixed with dark brown, coarse body hairs about 2 ins. long. When mohair figures in a blend it is commonly as mohair noils, which are the short fibers from the hair of the Angora goat, and the term mohair is rather expansive, as it covers the fleeces of a large number of Angora crosses. Its color is usually white, more rarely gray, and the fiber has a fine, curly texture of high luster, and an average length of 5 to 6 ins.

Alpaca noils are the short fibers from the combing of alpaca wool. This group embraces the llama, the vicuña, and the guanaco, all of which, however, are less important than the alpaca from the fiber point of view. For fancy yarns silk noils are used in combination with wool. These

are the short waste obtained from combing or carding spun silk. Both silk and cotton must be entered into a woolen blend only after the wool fibers have been oiled. The reason for this is that if the oil comes directly into contact with either silk or cotton it prevents the fibers from opening out freely during the carding process. Skin wool, or pulled wool, which, as previously stated, is that taken from the pelts of dead animals, has generally to be blended with other and better grades of wool.

The mixing of a blend is done by carefully building up a stock of the raw material on the floor of the mixing room, placing the different fibers in thin layers one on top of another. For example, in a mixture of wool, cotton, and shoddy, a layer of wool a few inches thick is first laid down, covering some square yards of the floor. Over this an even layer of a few inches of cotton is placed, followed by a similar layer of shoddy, and these successive layers are repeated and leveled up by the use of long rods, so that a pile two yards high is often reached, covering an area of many square yards, since the larger the mixing the more uniform will be the fabrics produced from it. When great extremes in fiber length have to be mixed, some medium lengths should be present, so as to unite them properly. In a case of this sort the order of mixing would be the short and medium first, then a blending of this with the longer fibers. Or, supposing three lengths of staple to be blended, by mixing one-half of the quantity of the two lowest with the longest, and the remainder with the shortest, two lots of a mixture are obtained which can be easily dealt with separately in the mixing picker, and afterward the two can be mixed together as if dealing with only two grades of material.

After building up the pile layer by layer, the pulling for the mixing picker is done by taking armfuls all along one side, from top to bottom, keeping the sides of the pile perpendicular by pulling straight down to the bottom. Only by this method can a thorough mixing be obtained, and if a very small quantity requires blending with a larger, the best method is to make a temporary mix of equal parts of the two, and then build this up into a stack with the larger constituent.

18. Conditions Affecting Quality of Wool.—The quality of wool obtained from sheep depends very largely on the breed, climatic conditions and nature of the pasturage on which the sheep feed. Other conditions being equal, long droughty seasons in wool-growing districts will cause the fiber to be much shorter than otherwise.

Australia appears to possess the climatic conditions best adapted for wool-growing. The wool fiber appears to grow to best advantage in a temperate climate, and when the sheep are provided with dry foods and pasture upon light soils. Rain-falls have a great influence on the wool fiber; fine merino wools being grown best where the rain-fall is slight, while the fiber tends to become coarse where the rain-fall is heavy. Aus-

tralia has a temperate climate, a light soil, and the average rain-fall is only 2 to 3 ins. With regard to the nature of the pasturage it has been found that grass from chalky soils gives rise to a coarse wool, whereas that from rich, loamy soils produces fine grades of wool. As a rule, the sheep which yield the best qualities of wool give the poorest quality of mutton. Utah wools, for instance, are harsh and stairy compared to Wyoming wools. This is due to the alkali in the soil in Utah and the dryness of the climate. The alkali in the soil and the effect it has upon the water which the sheep drink have a tendency to take the life out of the wool and weaken the staple. The more close and uniform the fibers lie, the better will be the combing qualities of the wool. The Utah wools in this respect are inferior to those of Wyoming, Idaho, and Montana, especially the wools grown in southern Utah. In northern Utah the wools are longer than in southern Utah, but there are very few Utah wools, either north or south, which are fit for combing. The wools of heaviest shrinkage generally come from eastern Oregon and Nevada. The degree of shrinkage depends to a considerable extent on the season in which the wools were grown. A wet season and long-continued rains will wash much dirt and dust out of the wools, thus leaving them lighter. The wools of lightest shrinkage come from Virginia and Kentucky and the Blue Grass region, where medium wools are grown, where the sheep are cleaner, the range better, and the country hilly, and where comparatively little sand and dirt work their way into the fleece. The shrinkage of washed fleeces ranges from 55 to 35 percent. Unwashed Indiana wools shrink 38 to 43 percent. Missouri wools will shrink around 43 to 45 percent; those of Illinois, 45 to 47 percent. California wools shrink 55 to 72 percent, depending on the part from which they come. The heaviest shrinkage wools

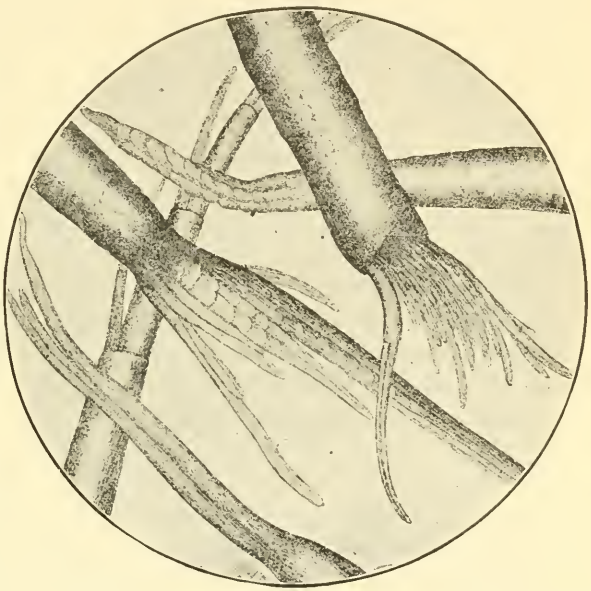


FIG. 71.—Wool Fibers Showing Abnormal Growth at Ends with Removal or Lack of Scales.

are in southern California, because of the presence of more sand and dirt, and inferiority of the range. Texas Spring wools shrink anywhere from 64 to 72 percent, and the Fall wools 58 to 64 percent. Territory wools shrink from 55 up to 73 percent. Idaho wools on the medium order will not shrink over 55 percent. Wyoming wools on the fine and fine medium order shrink 65 to 72 percent. The Montana wools shrink on the average 63 to 69 percent for fine and fine mediums, and 57 to 60 percent for mediums. The shrinkage on Arizona wools will range from 66 to 73 percent, but they will spin to finer counts than the Utah wools, and will scour out very white. In this latter respect the Wyoming wools are superior to any other grown west of the Mississippi River. The shortest wools grown in America are from California and Texas; they are used principally for felts and hats, though they can also be mixed in certain proportions with clothing wool. As the Territory wools are grown mostly in dry climates, they will gain somewhat in weight on being shipped to the Atlantic seaboard and stored for a few months. Utah wools will gain about 1 percent, Montana wools about $\frac{3}{4}$ percent, and Wyoming wools about 1 percent. The wools from Ohio and other eastern States will not gain anything; in fact, will sometimes show a slight shrinkage.

Unhealthy conditions of the sheep almost always influence the fiber during that period of its growth. If the sheep, for example, is suffering from indigestion, cold, lack of proper nourishment, etc., the fleece during that time will develop tender fibers; when the sheep regains its normal condition of health the fiber becomes strong again. Thus the fleece may have tender strata through it which will considerably affect the fiber and its uses. These tender spots, of course, render the wool unfit for combing purposes, and it must go into the "clothing" class, and will consequently sell for less money, other things being equal. It is no great injury to the wool, however, aside from spoiling it for combing, as the wool, after it has passed the tender spot, grows fully as well as before the sheep was ill.

When sheep have been afflicted with scab, the latter shows itself in tender wool at the bottom of the fiber. The scab leaves a puslike substance which adheres to the bottom of the fibers and dries there. Vermin on sheep have an influence on the wool; these creatures leave discolorations on the fiber which cannot be removed by scouring. The wool, being "off color," does not sell as well, and, moreover, the fiber is liable to be tender.[1]

[1] The dipping of wool on the sheep's back is almost a necessity, to overcome the harmful influence of ticks, lice and other insects and vermin, which would tend to produce scab. A good dip may also lubricate the fiber, giving it softness and elasticity, and may even improve the color by slightly bleaching it; but many dips have proved to be harmful to the wool, making it weak and brittle, stunting its proper

19. Influence of Manufacturing Operations on Quality of Wool.—While the woolen manufacturer is interested primarily in the strength and quality of the wool fiber as such in the preparation of the fabric, the consumer or user of the fabric itself is more interested in the strength and quality of the made-up material. There are many factors which enter into this phase of the question, chiefly depending on the nature of the

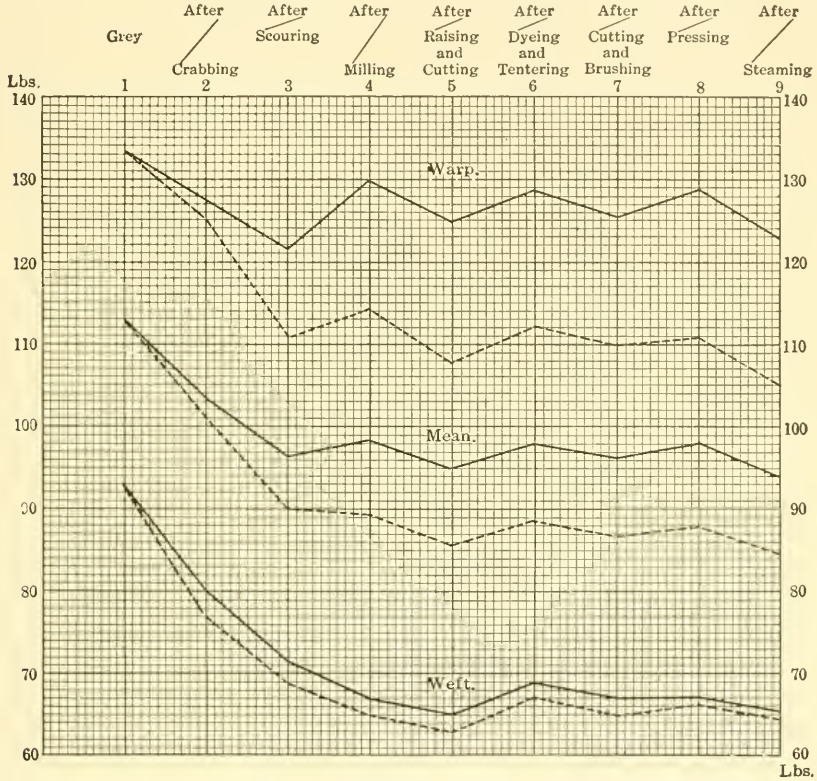


FIG. 72.—Influence of Finishing Operations on Tensile Strength of Woolen Fabrics. (Midgley.)

finishing processes as well as the care with which they have been carried out. It makes little difference how fine in quality the original wool fiber may have been if its good qualities have become affected by the various manufacturing processes through which the wool has been carried in the making of the cloth. Woolen fabrics are more likely to suffer than worsted fabrics, and it is on the experience and workmanship of the finisher that a great deal depends.

growth, and giving it a bad color. Among the harmful dips may be included lime and sulfur combinations, tobacco mixtures and pitch oil compositions. The most satisfactory dips are considered to be arsenical preparations and carbolic acid with oil.

VARIATION OF AN ALL-WOOL FABRIC AFTER THE VARIOUS FINISHING OPERATIONS

Dyed Indigo Blue, Vicuña Finish

		Counts of Warp.	Threads per Inch.	Length of Warp. Yards.	Width. Inch.	Counts of Filling.	Picks per Inch.	Weight of Warp and Filling.	Total Weight. Pounds.	Relative Strength and Elasticity.			
										Warp.		Filling.	
										Strength. Pounds.	Elasticity, Inch.	Strength. Pounds.	Elasticity, Inch.
0	Loom particulars	2/56's Botany	104	70	69¾	40 sk, woolen	100						
1	As received by the finisher	2/50	111	62½ (of cloth)	66	36 sk.	101	32½ lb. warp, 45½ lb. filling	78	141	1¾	95	1⅜
2	After crabbing and scouring	2/52	122	60	60	35 sk.	107	30 lb. warp, 43 lb. filling	73	134	1¾	77	1¾
3	After milling	2/54	124	60	59	35 sk.	107	29 lb. warp, 42½ lb. filling	71½	142	1⅜	72	1¾
4	After raising and cutting	2/54	124	60½	59	36 sk.	106	29½ lb. warp, 41 lb. filling	70	137	1½	66	1⅜
5	After dyeing and tentering	2/51	126	60	58	35 sk.	107	30½ lb. warp, 42 lb. filling	72½	140	1¼	72	1⅜
6	After cutting	2/51	126	60	58	35.5 sk.	107	30½ lb. warp, 41¼ lb. filling	71¾	132	1¼	69	1½
7	After pressing	2/53	126	61½	58	35 sk.	104	30½ lb. warp, 41¼ lb. filling	71¾	137	1¼	68	1½

Observations:

Total loss in weight = 8 percent { 6 percent loss of worsted. / 10 percent loss of woolen. }

Shrinkage in width = 17 percent.

Shrinkage in length = 12 percent.

ILLUSTRATING THE LOSS OF WEIGHT INCURRED DURING FINISHING "WOOLENS"

	Type of Cloth.	Finish.	Warp.	Filling.	Weight.	Loss in Weight, Percent.
1	Vicuña	Heavily milled	Woolen yarn, low quality	As Warp	21½ oz.	24
2	Trousering	Clean finish	Colored worsted and cotton twist	Black woolen, low quality	16 oz.	17
3	"	" "	Ditto	Ditto	16 oz.	16¾
4	Mixture coating	Tweed finish	24 cut Gala (mixture), 44 threads per inch	As warp	17 oz.	10
5	" "	" "	2/24 cut Gala (mixture), 30 threads per inch	As warp	18 oz.	10
6	Trousering	Slightly milled	30 sk. colored woolen, good quality, 68 threads per inch	As warp. 64 picks per inch	17 oz.	10
7	Low melton	Heavily milled	2/40 cotton, 40 threads per inch	6 sk. low quality, 60 picks per inch	18 oz.	27
8	Carriage rug	Velvet finish	2/20 cotton, 18 threads per inch	Colored 5sk. woolen, medium quality	3½ lb.	20
9	Carriage rug	Velvet finish	Colored woolen yarn, low quality	As warp	4 lbs.	22
10	Amazon dress fabric	Milled and raised	1/36 mule spun worsted, 72 threads per inch	40 sk. woolen, fair quality, 36 picks per inch	—	13

The influence of various dyeing and finishing operations on the strength of woven cloth is quite important, and such influences are mostly due to the effect on the fiber of which the cloth is composed. Prof. E. Midgley (*Textile Manufacturer*) gives a plotted diagram of curves (Fig. 72) and tables representing the influences of various processes on the strength of woolen cloth.

To understand the various factors which play a part in this matter the following processes are discussed by a practical finisher (*Textile Manufacturer*) in their relation to their influence on the quality of the fabric.

Overheating.—The one cause of tenderness is overheating the goods during the fulling operation. A certain amount of heat is necessary in conjunction with the other essential conditions—namely, pressure, friction, and the lubricating and softening agency of the soap solution,—but an excess of heat is always to be avoided. A fabric composed of good, sound and strong woolen yarn may be considerably reduced in strength by adding more weight than necessary to the trap of the crimping box in an attempt to accelerate the process. The excessive weight causes great pressure and friction, and as friction gives rise to heat, the greater the friction, the greater the possibility of overheating the fabric. Heat

may also be generated to excess when the fulling is performed in too close or confined conditions, and this is most liable to occur in hot or sultry weather, if the necessary precautions to prevent such are not observed. In the winter, or during the cold weather, it often becomes necessary, in order to commence the felting and to perform the operation in a reasonable time, to confine the atmosphere of the fulling mill by preventing, to a considerable extent, the access of the cold outside air. This is accomplished by placing the box cover over the fulling rollers, adding the lids to the top of the fuller and closing the door of the machine during the fulling operation; thus the heat which is generated by the continual friction is confined to the fulling mill, and the process is accelerated. Naturally, in hot or sultry weather the tendency of the atmosphere is to increase rather than decrease the heat generated during the passage of the fabric through the machine. Hence, it is imperative that the fabric be ventilated as much as possible to avoid overheating, and the covers for the rollers and top of the machine are dispensed with, and the operation performed with the door open also. Investigation seems to prove that it is not entirely the excess of heat which causes tenderness, but rather the excess of heat combined with friction and pressure; also that the tenderness is not wholly due to a weakening of threads composing the fabric. Considering the question of heat first, there are processes—namely, scouring, dyeing, and boiling—in which a fabric may undergo treatment at a much higher temperature than that generated in the fulling mill without suffering materially in strength, providing the material is of good strength previous to treatment in these processes. Of the processes mentioned, it will be observed that only in the scouring does pressure and friction take place to any extent, and that in an inferior degree as compared with the pressure and friction during the fulling. What apparently takes place as overheating occurs is this: The fibers, under the influence of moisture and the high temperature, are rendered very soft and pliable, yielding freely to the vigorous action which always exists during fulling, and become partially detached from the body of the threads in considerable quantities, weakening the threads in consequence. Running the goods too dry during the fulling also frequently results in a light weakening of the fabric, not sufficient, however, to designate a piece as being tender. The lack of lubrication causes chafing, and waste in the form of flock is much in evidence on the guide board and on the trap of the crimping box immediately behind the fulling rollers.

Raising or Dressing.—To avoid tenderness during raising is one of the chief points which the finisher must bear in mind, during both the wet and dry processes, and if the desired smartness cannot be satisfactorily obtained without endangering the strength of the fabric, then the appearance to a certain extent becomes only a secondary consideration. A

fabric which is known to be weak previous to the commencement of raising (wet or dry) must be treated with special care, the teasels used must be weak or of only moderate strength, and, above all, the operation must be of a gentle character. Tenderness may be caused as a result of: (1) over-treatment; (2) using teasels which are too powerful, or when raising on the Mozer increasing the speed of the wire rollers rashly; and (3) lack of sufficient moisture. The term "over-raised" or "over-dressed" is invariably applied to any fabric which becomes tender during raising, whether the actual cause is directly due to over-treatment or not. A fabric which is rendered tender by over-raising generally conforms more nearly to the desired requirements—in wet raising, smartness and fineness of surface; and in dry raising, smartness and clearness of surface after the pile is removed—than is the case when the strength is reduced by the use of strong work or raising too dry. Over-raising is due to lack of proper judgment or attention on the part of the person responsible, whereby the treatment is unnecessarily prolonged, and though the strength of teasels or the speed of the wire rollers on the Mozer is correct, and the fabric sufficiently damp, an excessive amount of fibers become detached from the threads, which are in consequence weakened.

In order to obtain the best results during wet raising not only as regards fineness, smartness, and brilliancy of finish, but also to retain the strength of the material, a correct degree of moisture must be maintained throughout the operation. Excess of moisture retards the process, particularly when raising on a teasel gig, and the weak teasels which are employed at the commencement do little real work; consequently, the fabric is lacking in fineness of surface. Lack of moisture, however, is more to be feared, as the fibers when in a dry condition are brittle, unyielding, and more easily broken and torn from the threads, causing weakness, and flyings or flocks become more numerous. The cloths should be evenly cuttled and covered completely with a wet linen wrapper, and some little time before a fabric is required for raising it should be reversed to allow the water to drain evenly through. During raising, also, the lists should receive attention and be damped if required, and should it be necessary to cuttle the cloth on the scray before the process is completed, it should be covered with a damp wrapper as previously stated. Thin cloths in particular require careful attention in this respect.

Roll Boiling or Potting.—Sound, strong fabrics may receive as many as five or more distinct boils, each of at least six hours' duration at temperatures from 70° C. to 80° C., without any apparent loss of strength when tested by the usual methods in vogue in the factory. The majority of fabrics required to be roll-boiled are of the "dressed face" varity, and to guard against weakness during the boiling a few precautions are necessary. In the first place, the soft water in which the rolls are boiled should

be slightly acid; this is not only a safeguard against running colors, but a prolonged boiling in a slightly acid bath is far less injurious to the wool fibers than if the bath is neutral. Acetic is quite a safe acid to employ, and answers the purpose admirably in the proportion of 1 qt. of acid to 100 gals. water. The next and by far the most important step to be taken to prevent tenderness is with the rolling of the fabric. To obtain the best results from the roll boiling process as regards a lustrous surface it is essential that the fabric be rolled tightly. Now it is obvious that when the rolled fabric is immersed in the boiling tank, as the individual fibers absorb the water and thereby swell or attempt to swell, the roll of cloth becomes much tighter and firmer, and a great strain results on both the warp and weft of the fabric, and if the threads are not of sufficient strength to withstand the strain, they yield, and are thus further weakened, causing a tender cloth. Microscopic examination reveals the fact that wool fibers treated in water at high temperatures increase in diameter to a greater extent than when treated at the lower temperatures. Consequently, variation in the temperature of the water in which the boiling takes place is necessary when dealing with fabrics inclined to be tender. For if such fabrics are treated at the higher temperature, 160° F. to 180° F., then as the individual fibers attempt to expand, the strain occasioned may be such as to render the fabric tender. The temperature for such goods should not be higher than 140° F., for preference less, to perform the boiling with safety.

Carbonising.—The first process to be considered where the wool fibers may be directly attacked is the carbonising or the steeping stage of the carbonising process, in which the fabric is chemically treated to destroy extraneous vegetable matter. Providing the solution of dilute sulfuric acid is used at the correct strength there need be no fear of tenderness resulting. The solution should be at 6° Tw., and should not exceed this standard, or the strength of the fabric is placed in jeopardy, as the acid attacks the wool fibers. Tenderness as a result of the carbonising process can only arise through carelessness or negligence in preparing the acid bath.

Cutting.—The only cause of tenderness during the cropping or cutting operation is absolute carelessness or incompetence on the part of the cutterman, whereby the cutting portion is set too near the surface of the fabric, and instead of only removing the superfluous fibers, the fibers composing the threads which are uppermost are severed, weakening the fabric in consequence. Fabrics most liable to injury in this respect are those which require a close cropping, and as the majority of worsteds require a clear finish, these goods may be expected to suffer more than woolens.

CHAPTER V

THE CHEMICAL NATURE AND PROPERTIES OF WOOL AND HAIR FIBERS

1. Composition of Raw Wool.—In its chemical constitution wool is closely allied to hair, horn, feathers, and other epidermal tissues. A distinction must be made between the fiber proper and the raw wool as it comes from the fleece. In the latter condition it contains a large amount of dirt, grease, and dried-up sweat which have first to be removed by the scouring process before the pure fiber is obtained.[1]

The following analysis by Chevreul of a merino wool shows the average amount of fiber to be obtained from raw fleece wool:

	Percent.
Earthy matter deposited by washing the wool in water	26.06
Suint or yolk soluble in cold distilled water	32.74
Neutral fats soluble in ether	8.57
Earthy matters adhering to the fat	1.40
Wool fiber	31.23
	100.00

These figures are based on wool dried at 100° C.; if corrected for air-dry wool containing 14 percent of moisture, this would give only about 27.5 percent of pure fiber. Of course, the amount of fiber will vary considerably in different qualities and samples of wools, but this figure may be taken as a fair average.

[1] There is a bad practice in some sheep-raising districts of branding the sheep with tar. Many efforts have been made by manufacturers to point out to farmers that irremediable damage is done to the wool from the manufacturing point of view, as this tar cannot be removed in ordinary scouring processes, but has to be cut out of the fleece as waste. Small pieces of tar left on the wool cause immense damage in subsequent operations, because the fibers of the wool are caused to adhere firmly together during the opening operations. This method of branding is entirely unnecessary, as a harmless branding liquid is now in existence which can be easily scoured out in ordinary washing operations. A warning is issued in regard to using a branding liquid which may have been stored in a phosphate tin, for this causes the substance to attack and burn the wool and the fleece has to be clipped from the sheep.

Wright [1] gives the following analyses of greasy wools:

Constituents.	Half Blood.	Three-quarter Blood.	Leicester.	Lincoln.
Moisture	16.90	19.30	17.97	17.18
Wool-fat	16.68	12.08	8.94	5.72
Other fatty matter	0.42	0.74	0.91	0.96
Water soluble suint	10.30	12.72	7.81	2.26
Sand, dirt, etc	3.62	3.92	5.10	5.32
Pure wool fiber	52.08	51.32	59.45	68.56

Barker (*Encyl. Brit.*) gives the following list of the yield in clean wool of the chief commercial varieties:

Type of Wool.	Yield in Percent.
Australian merino	50
Cape	48
South American merino	45
New Zealand cross-bred	75
South American cross-bred	75
English Southdown	80
English Shropshire	80
English Lincoln	75
Mohair	85
Alpaca	85

2. Wool Grease; Cholesterol.—The fatty and mineral matters present on the raw wool fiber consist on the one hand of wool grease derived from the fatty glands surrounding the hair follicle in the skin, and on the other hand of dried-up perspiration from the sudorific glands in the skin. The wool grease is mostly to be found as the external coating on the fiber which serves to protect it from mechanical injury and felting while in the growing fleece. The statement made in some text-books that raw wool when left in the greasy condition is not attacked by moths is erroneous. The personal experience of the author has proved that raw wool is as liable to the depredations of insects as washed and scoured wool.

Lack of natural grease on the fibers of the growing fleece results in the production of so-called *cotted* fleeces. In such fleeces the fibers have grown in and among eacl other on the sheep's body, so that they form a more or less perfect mat of wool. These mats are hard or soft according to the extent to which the matting process has been carried on. Cotted fleeces occur mostly in sheep which have been housed; they are seldom found in the territories where the sheep run on the range and are more

[1] *Jour. Soc. Chem. Ind.*, 1909, p. 1020.

exposed and hardy. Cotted fleeces indicate a low degree of vitality, and many are to be found in fleece wool from States east of the Mississippi River. They may be caused by sickness or a low state of the blood, or they may be found in an old sheep which is giving out or is run down, which contributes to the frowsy condition of the wool. Cotted fleeces are unfit for combing purposes, as they have to be torn apart, and frequently they are so dense and hard that the fibers can only be pulled apart by the use of special machinery. Badly cotted fleeces are frequently used for braid purposes.

There is also a small amount of oily matter contained in the medullary intercellular structure of the fiber which appears to have the function of acting as a lubricant for the inner portion of the fiber, thus preserving its pliability and elasticity.

Wool grease does not appear to be a simple compound, but evidently consists of several oils and wax-like compounds. Its chief constituent is cholesterol, which appears to be one of the higher monatomic alcohols, and is not a glyceride. Analysis shows it to have the formula $C_{26}H_{43}OH$. It is a solid wax-like substance which very readily emulsifies in water. Associated with cholesterol there is also an isomeric body called *isocholesterol*. Besides these solid waxes, wool grease also contains two fats which have been studied by Chevreul to some extent. These are described as follows:

(*a*) *Stearerin*, a neutral solid fat, melting at 60° C.; contains neither nitrogen nor sulfur; does not emulsify with boiling water, but emulsifies without saponification when boiled with caustic potash and water; it is soluble in 1000 parts of alcohol at 15.5° C.

(*b*) *Elairerin*, a neutral fat melting at 15.5° C.; also free from nitrogen and sulfur; it emulsifies with boiling water, and is saponified with caustic potash; it is soluble in 143 parts of alcohol at 15.5° C.

3. Suint.—The dried-up perspiration adhering to the raw-wool fiber is also called suint. It consists principally of the potash salts of various fatty acids, and it is soluble in water, therein it differs from wool grease. On extraction with water, suint will yield a dry residue of about 140 to 180 lbs. for 1000 lbs. of raw wool. This on ignition will give 70 to 90 lbs. of potassium carbonate and 5 to 6 lbs. of potassium sulfate and chloride, so that the amount of potash salts to be derived from raw unwashed wool may be taken to be about 10 percent on the weight of wool.

Maumené and Rogelet give the following analysis for the inorganic constituents of suint:

	Percent.
Potassium carbonate	86.78
Potassium sulfate	6.18
Potassium chloride	2.83
Silica, phosphorus, lime, iron, etc	4.21

The yield, however, of potash salts that may be recovered from wool suint is very variable, owing to the different character and proportion of the suint in different lots of fleece wools. Stirm (*Die Gespinstfasern*, p. 143) gives the following figures obtained in practice (at Döhren); 5000 lbs. of raw wool gave 142 lbs. of raw potash salts having the following composition:

	Percent.
Potassium carbonate	78.5
Potassium chloride	5.7
Potassium sulfate	2.8
Sodium sulfate	4.6
Insoluble matter	5.0
Organic matter	3.0

According to Märker and Schulze [1] the ash of two representative samples of wool suint had the following composition:

	Percent. (I)	Percent. (II)
Potassium oxide (K_2O)	58.94	63.45
Sodium oxide (Na_2O)	2.76	Trace
Calcium oxide (CaO)	2.44	2.19
Magnesium oxide (MgO)	1.07	0.85
Iron oxide (Fe_2O_3)	Trace	Trace
Chlorine (Cl)	4.25	3.83
Sulfuric acid (SO_3)	3.13	3.20
Phosphoric acid (P_2O_5)	0.73	0.70
Silicic acid (SiO_3)	1.39	1.07
Carbonic acid (CO_2)	25.79	25.34

4. Ash of Wool Fiber.—Besides the mineral matter existing in the soluble suint, there is also a small amount of mineral matter which appears to form an essential constituent of the fiber itself. It is left as an ash when wool is ignited, and amounts on an average to about 1 percent, the majority of which is soluble in water and consists of the alkaline sulfates. The following analysis by Bowman shows the typical composition of the ash of Lincoln wool:

	Percent.
Potassium oxide	31.1
Sodium oxide	8.2
Calcium oxide	16.9
Aluminium oxide, Ferric oxide	12.3
Silica	5.8
Sulfuric anhydride	20.5
Carbonic acid	4.2
Phosphoric acid	Trace
Chlorine	Trace

[1] *Jour. Prakt. Chem.*, vol. 108, p. 193.

Arsenic appears to be present in nearly all samples of wool, even in the natural state. The arsenic is generally derived from the dips to which the sheep are subjected. Even the wool from a lamb whose mother has been dipped a considerable time before the lamb's birth will show distinct traces of arsenic. Thorpe gives the following figures for the amounts of arsenic in woolen materials:

	Arsenious Oxide Mgms. per Gram of Material.
Flannel from natural wool	0.005–0.009
White Berlin wool	0.037
Cream flannel	0.004
Welsh flannel	0.015
Vest wool (undyed)	0.011
Linen (white)	Free
Silk (undyed)	0.001
Wool from lamb (mother treated with arsenical dip)	0.0005
Wool from lamb (mother dipped shortly before birth of the lamb)	0.019
Wool from ewe (treated with carbolic dip 15 months previously)	0.047

5. Coloring Matter.—Sheep's wool is nearly always white in color, though sometimes it may occur in the natural colors of gray, brown, or black.

There do not appear to be any laws regulating the occurrence of black wool in sheep. Beyond the difference in color there is not any noticeable difference in structure or properties between black wool and ordinary wool. Climatic conditions do not seem to have any influence on the production of black wool, and it is as liable to occur in one breed as in another. It would be thought the question of heredity would have an important bearing on the origin of black wool; but even this factor appears to be without influence, as a black lamb may have both parents white, both black, or one white and one black. The amount of black wool appearing in the American domestic trade is about 3 to 5 percent of the total clip. It is used almost exclusively in the undyed condition for the production of gray mixes for hosiery and underwear.

The *coloring matter* in wool appears to withstand the action of alkalies and acids, though it is not especially permanent toward light. It appears to be distributed in the fiber in quite a different manner from that of the artificially applied dyes. The natural coloring matter appears to be contained particularly in the cells of the cortical layer and the marrow in a granular form, and to occur to a greater extent in the medullary than in the cortical cells. In fibers which are only slightly colored the walls of the cells are almost colorless; though when the fiber becomes very strongly

colored the cell-walls also appear to be impregnated with the coloring matter. In wools which have been dyed, however, the cell-walls are nearly always uniformly colored, in consequence of which the medulla of the fiber becomes less pronounced; whereas, with naturally colored wools, the medulla is usually rendered more distinct through the deposit of coloring matter.

6. Chemical Constitution of Wool; Keratine.—The wool fiber has been found to consist of five chemical elements—namely, carbon, hydrogen, oxygen, nitrogen, and sulfur. Nitrogen is an ingredient common to both wool and silk, but sulfur is distinctly characteristic of wool and hair fibers.

In its chemical nature wool is classed as a *proteid*, known as keratine. As its constituents are not rigidly constant in their proportions, we cannot assign to wool a definite chemical formula.

On an average, its composition may be taken as follows:

	Percent.
Carbon	50
Hydrogen	7
Oxygen	26–22
Nitrogen	15–17
Sulfur	2– 4

Keratine, free from ash, water, and melanine, on hydrolysis, gave the following amounts of monamino-acids:[1]

	Keratine from Horsehair, Percent.	Keratine from Goose-feathers, Percent.
Glycine	4.7	2.6
Alanine	1.5	1.8
Amino-valeric acid	0.9	0.5
Leucine	7.1	8.0
Pyrolidine-2-carboxylic acid	3.4	3.5
Aspartic acid	0.3	1.1
Glutaminic acid	3.7	2.3
Tyrosine	3.2	3.6
Serine	0.6	0.4

According to the tables of Colnheim, the percentages of known constituents in the keratine from hair are as follows:

	Percent.
Leucine	14
Glutaminic acid	12
Aspartic acid	Not determined
Cystine	13.92
Tyrosine	3
Ammonia	Large amount

[1] Abderhalden, *Zeit. physiol. Chem.*, vol. 46, p. 31.

Bowman gives the following analyses of four different grades of English wool:

Constituent.	Lincoln Wool.	Irish Wool.	Northumberland Wool.	Southdown Wool.
Carbon	52.0	49.8	50.8	51.3
Hydrogen	6.9	7.2	7.2	6.9
Nitrogen	18.1	19.1	18.5	17.8
Oxygen	20.3	19.9	21.2	20.2
Sulfur	2.5	3.0	2.3	3.8
Loss	0.2	1.0		

These analyses were made of wool which had been purified by extraction with water, alcohol, and ether.

Abderhalden and Voitinovici [1] give the following animo bodies obtained from decomposition products of wool:

	Percent.
Glutaminic acid	12.9
Leucine	11.5
Cystine	7.3
Alanine	4.4
Proline	4.4
Tyrosine	2.9
Valine	2.8
Aspartic acid	2.3
Glycocoll	0.58
Serine	0.1

The wool fiber as a whole does not appear to be a homogeneous chemical compound; instead of being a simple molecular body to which a definite formula might be given, it is doubtless composed of several chemically distinct substances. This is evidenced by the fact that the proximate constituents of wool are by no means constant in their amount; furthermore, certain of its constituents are in part removed by simply boiling the fiber in water without a structural disorganisation taking place. The sulfur content is especially liable to fluctuation, and is the most readily removed of the chemical elements of which the fiber is composed; in fact, so easily is some of the sulfur removed as such by various solvents, that it would seem to indicate that this constituent existed in wool either in the free condition or in a compound of exceedingly unstable character.

Schuetzenberger, by decomposing pure wool fiber by heating with a solution of barium hydrate at 170° C., obtained the following decomposition products:

[1] *Chem. Central-Blatt*, 1907, p. 707.

	Percent.
Nitrogen (evolved as ammonia)	5.25
Carbonic acid (separated as barium carbonate)	4.27
Oxalic acid (separated as barium oxalate)	5.72
Acetic acid (by distillation and titration)	3.20
Pyrol and volatile products	1 to 1.50
Proximate composition of fixed residue, containing leucine, tyrosine and other volatile products	C 47.85 H 7.69 N 12.63 O 31.18

Williams has shown that by distilling wool with strong caustic potash a large amount of ammonia was obtained in the distillate, together with butylamine and amylamine. Dry distillation of wool yields an oil of a very disagreeable odor, probably consisting of various sulfuretted bases; also a considerable amount of pyrol and hydrogen sulfide gas, together with a small amount of carbon disulfide, and traces of various oily bases.

7. Nitrogen in Wool.—The presence of nitrogen in wool is readily made evident by simply burning a small sample of the fiber, when the characteristic empyreumatic odor of nitrogenous animal matter will be observed. By heating wool in a small combustion test-tube it will be noticed that ammonia is among the gaseous products evolved, and can be tested for in the usual manner.

Schuetzenberger has shown that the products of the hydrolysis of wool by baryta-water are analogous to those of albuminoids containing amino groups; the experiments of Prud'homme [1] and Flick also indicate the presence of imino rather than amino groups in wool. The fact that wool absorbs nitrous acid, and combines with phenols, which is supposed to indicate the presence of amino groups, may be explained by the formation of nitrosamines with the imino groups, which would also yield colored derivatives with phenols. Saget [2] supports the theory that wool contains amino, imino, and carboxyl groups, claiming that this constitution is required to explain why wool mordanted with tannate of tin loses its affinity for acid dyes.

8. Lanuginic Acid.—The amino acid of keratine has received the name of lanuginic acid, and has been prepared by dissolving purified wool in a strong solution of barium hydrate, precipitating the barium by means of carbon dioxide, and after filtering, treating the liquid with lead acetate, whereby the lead salt is obtained. This is decomposed by means of hydrogen sulfide, and the lanuginic acid obtained, after evaporation, as a dirty-yellow substance. Its solution in water yields colored lakes with the acid and basic dyestuffs, and also with the various mordants. Champion [3] gives the formula of lanuginic acid as $C_{19}H_{30}N_5O_{10}$, but Knecht

[1] *Rev. Gen. Mat. Col.*, 1898, p. 209.
[2] *Monit. Scient.*, 1910, p. 80.
[3] *Compt. rend.*, vol. 72, p. 330.

and Appelyard[1] reject this formula, as they show that the compound contains about 3 percent of sulfur.

According to Knecht, lanuginic acid possesses the following properties: It is soluble in water, sparingly so in alcohol, and insoluble in ether. Its aqueous solution yields highly colored precipitates with the acid and basic dyestuffs; tannic acid and bichromate of potash also give precipitates. The following mordants in the presence of sodium acetate also give precipitates: Alum, stannous chloride, copper sulfate, ferric chloride, ferrous sulfate, chrome alum, silver nitrate, and platinum chloride. Lanuginic acid exhibits all the properties of a proteoid, and may therefore be classed among the albuminoids; it is soluble in water at all temperatures, and its solution is not coagulated. With Millon's reagent and with the double compound of phosphoric and tungstic acids, it shows the characteristic albuminoid reactions. Knecht recommends the use of a solution of wool in barium hydrate for the purpose of animalising vegetable fibers. Cotton so treated is capable of being dyed with acid and basic dyestuffs.

When heated to 100° C., lanuginic acid becomes soft and plastic, and the majority of its colored lakes also melt at this temperature. Knecht gives the following analysis of lanuginic acid:

	Percent.
Carbon	41.61
Hydrogen	7.31
Nitrogen	10.26
Sulfur	3.35
Oxygen	31.44
	93.97

Though lanuginic acid contains a notable amount of sulfur in its composition, it is not blackened by treatment with sodium plumbite.

9. Browning of Wool.—Fort[2] has studied the development of a brown color on wool through exposure and other agencies, and has come to the conclusion that the browning of wool by exposure is largely due to the degradation of the free amino compounds which may be present at the start and which may also be developed in the wool by exposure. Wool which has been exposed shows a greater tendency to go brown when afterwards heated, steamed, boiled, or treated with alkalies, as these treatments all develop free amino groups in wool. The similar development of an increased affinity for acid dyes after wool has undergone exposure or any of these treatments, and the increased reaction with naphthoquinone sulfonate supports the belief that a development of amino groups takes place. The brown color produced by these agencies may be considerably removed by acid treatment or stoving, while a preliminary treatment of

[1] *Jour. Soc. Dyers & Col.*, 1889, p. 71.

[2] *Jour. Soc. Dyers & Col.*, 1916, p. 184.

the wool with sulfuric acid renders it less liable to go brown under any of these treatments. The properties of "faded" wool as distinguished from fresh wool are seen in the dyeing of worn garments, where often the reaction of the wool with the dyestuff is not at all the same as it would be with fresh wool. Also if wool fabrics are partly exposed and partly protected for a considerable period of time and then dyed, streaks will develop. Fade marks are also liable to develop on wool fabrics which have been boiled or steamed for the production of luster and spot-proof finishes.

10. Sulfur in Wool.—The presence of sulfur in wool can be shown by dissolving a sample of the fiber in a solution of sodium plumbite (obtained by dissolving lead oxide in sodium hydrate), when a brown coloration will be observed, due to the formation of lead sulfide. On adding hydrochloric acid to the solution and heating, the odor of sulfuretted hydrogen will be distinctly noticed. The application of this test to show the presence of sulfur in wool is sufficient to discriminate chemically between that fiber and those consisting of silk or cotton, and also to detect wool in admixture with other fibers.

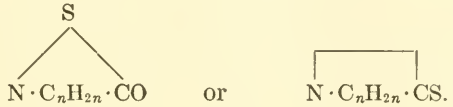
The older methods of hair-dyeing were based on this same reaction, solutions of soluble lead salts, such as sugar of lead, being applied to the hair, with the result that lead sulfide would be formed and cause a dark-brown coloration. The use of such preparations, however, is dangerous, as they are liable to cause lead-poisoning.

The presence of sulfur in wool may at times be the cause of certain defects in the dyeing process. In neutral or alkaline baths, if lead is present, the color obtained on the fiber will be more or less affected by the lead sulfide formed on the wool, and serious stains may be the result. The presence of sulfuric acid, however, prevents this, and no staining of the fiber takes place. Stains are sometimes produced when wool is mordanted with stannous chloride, as in the dyeing of cochineal scarlets, due to the formation of stannous sulfide. Occasionally woolen printed goods exhibit brownish stains on the white or light-colored portions after being steamed. These may be due to slight traces of copper or lead which have been deposited on the cloth during its manipulation and passage through the machines, these metals, when the wool is steamed, forming dark-colored sulfides which cause the stains. By locally applying a weak solution of hydrogen peroxide such discolorations may be removed without injury to the prin ed color.

Chevreul recognised the fact that in certain dyeing operations it was necessary to remove the sulfur from wool as far as possible in order to obtain the best results. He accomplished this by steeping the wool in milk of lime and afterward in a weak bath of hydrochloric acid, and finally washing.

The amount of sulfur existing in wool does not appear to be a very constant factor, but varies in different samples of wool from 0.8 to 4 percent. Wool is similar to other albuminoids in that it contains a relatively small though a widely fluctuating amount of sulfur. The following sulfur compounds have been isolated from the decomposition products of the albuminoids: Cystine, cysteine, thiolactic acid, thioglycollic acid, ethyl sulfide, ethyl mercaptan, sulfuretted hydrogen, and diethyl-thetine. The manner in which the sulfur exists in the molecular structure of the fiber is by no means clear, as the majority of it is readily removed without any apparent structural modification of the fiber itself. According to Chevreul the amount of sulfur in wool was reduced to 0.46 percent by several treatments with lime-water. Treatment with a concentrated solution of caustic soda in such a manner as not to disintegrate the fiber will remove as much as 84.5 percent of the sulfur originally present in the wool. On a sample of wool containing 3.42 percent of sulfur, treatment in this manner left only 0.53 percent of sulfur in the fiber. This would appear to indicate that the sulfur is not a structural constituent of the wool fiber. The presence of sulfuric or sulfurous acids has formerly never been observed in the decomposition products of albuminoids and this led to the opinion that the albumin molecule did not contain sulfur in combination with oxygen. Raikow,[1] however, finds that when purified unbleached wool is treated with phosphoric acid considerable quantities of sulfurous acid are evolved. The fact, however, that the sulfur present is not all removed by even such severe treatment as described would also serve to indicate that this element may exist in wool in two forms, the one an ultimate constituent of the fiber, and the other, and major part, as a more loosely combined compound. The fact that the amount of sulfur naturally present in wool is by no means constant would also tend to support this view; as would also the fact that the major portion of the sulfur is so readily split off to form metallic sulfides. On dissolving wool in boiling caustic soda, it does not appear that all of the sulfur is converted into sodium sulfide, as only about 80 percent of it can be obtained as hydrogen sulfide when the caustic soda solution is treated with acid. Probably the remainder of the sulfur exists in the wool as a sulfonic acid, or some compound of a similar nature.

According to Prud'homme [2] the sulfur in the wool is probably combined either as



[1] *Chem. Zeit.*, 1905, p. 900.
[2] *Rev. Gen. Mat. Col.*, 1898, p. 209.

It is also contained in the natural coloring matter of the wool.

White gives the following method for the determination of sulfur in wool: Digest 1 gram of wool with caustic soda solution and lead acetate, acidify with acetic acid and further digest, filter and was the precipitated lead sulfide. Decompose the latter together with the filter paper with hydrochloric acid (conc.), make alkaline with caustic soda, and then acidify with acetic acid and filter. Determine the lead in the filtrate as chromate in the usual manner. The method is said to give concordant and accurate results.

11. Hygroscopic Quality.—Wool is more hygroscopic than any other fiber, but the amount of moisture it will contain will vary considerably according to the humidity and temperature of the surrounding atmosphere. Under average conditions, however, it will contain from 12 to 14 percent of absorbed moisture. The hygroscopic quality of wool is a subject of considerable importance in the commercial handling of this fiber, for the weight of any given lot of wool will vary within large limits in accordance with climatic conditions; that is to say, the shipment of wool from one locality to another of different humidity and temperature will cause a loss or gain in the apparent weight of the material.[1] So important a

[1] In this connection the Wyoming Experiment Station has made some interesting studies (*Bulletin* 132), the results of the experiments being summarised as follows:

Small samples of wool transferred in the summer from Laramie, Wyoming, to the suburbs of Washington, D. C., had increased 4 or 5 percent in moisture content shortly after arriving at their destination. Fifty-gram samples exposed to the outdoor air at Laramie, Wyoming, in August underwent wide variations in moisture content in response to the fluctuations in the temperature and relative humidity of the air, changes of moisture content as high as 6 percent having taken place in less than twenty-four hours. It was found that as compared to the pure wool fiber exposed to the same conditions, unwashed wool that was comparatively free from insoluble earthy matter, absorbed more moisture and was more affected by changes in the moisture of the air. It was also found that on the same basis of comparison, wool containing a high percentage of sand absorbed less moisture and was less affected by changes in the air. A detailed analysis of the hygroscopic properties of the pure fiber and natural impurities of a sample of Leicester wool showed that if the percentage of moisture in the sample was called 1, then the suint was 2 to $2\frac{1}{2}$, the wool-fat $\frac{3}{4}$ to $1\frac{1}{2}$ and the insoluble dirt which, in this case, consisted of a small amount of clay and finely powdered vegetable matter, was 1. Drying once to a constant weight did not measurably affect the power to re-absorb the normal amount of moisture. A sample of wool that has been exposed to an atmosphere with a high relative humidity upon being brought into one of lower relative humidity comes into equilibrium with the latter by losing weight at a rate directly in proportion to the area of surface exposed, and the rate of change to a given area of surface is a direct function of the difference between the regain of the wool and its normal regain for the air surrounding it. A few conclusions with a practical application may be drawn from this summary and the work preceding it. The first one has long been known to practical wool men, namely, that wool from the Mountain States gains in weight upon being stored in warehouses along the Atlantic seaboard. A second one is that the greater the pro-

factor has this become in the commercial relations between wool-dealers, that conditioning houses for wool have been established in many European centers for the purpose of carefully ascertaining the actual amount of fiber and moisture present in any given lot of wool, the true weight being based on a certain standard percentage of moisture, or so-called "regain." This percentage varies somewhat with the character of the material and also the conditioning house, ranging from 16 to 19 percent. The hygroscopic quality of wool also has an important bearing on the spinning and finishing processes for this fiber, it being necessary to maintain a definite and uniform condition of moisture in order that the best results be obtained in the spinning of yarns and the finishing of the woven fabric.

Wright [1] as the result of an investigation of the absorption of moisture by wool arrives at the conclusion that the amount of moisture which a wool can absorb from the atmosphere depends on several factors, as follows: (1) The relative humidity of the atmosphere. (2) Pure wool fiber, of which greasy wool contains about 50 percent, can absorb from 18 to 20 percent of its weight of moisture from the atmosphere, but this amount is not sufficient to account for all the moisture absorbed by the dry normal wool fiber. (3) Natural wool-fat, present in greasy wool to the extent of about 17 percent, is capable of absorbing about 17 percent of its weight of atmospheric moisture. (4) Suint, or wool perspiration, is present in greasy wools to the extent of about 13 percent, and is very hygroscopic, absorbing 60–67 percent of moisture.

12. Water of Hydration in Wool.—The wool fiber also appears to possess a certain amount of water of hydration, which is no doubt chemically combined in some manner with the fiber itself; for it has been observed that wool heated to above 100° C. becomes chemically altered through a loss of water at that temperature. This will no doubt explain the fact that air-dried wool is superior in quality to that dried by means of artificial heat, which usually signifies a rather elevated temperature. According to Persoz, the destructive action of high temperatures on the wool fiber may be prevented by saturating the material with a 10 percent solution

portion of sand in the wool, the less this gain in weight caused by storage at the seaboard, will be. A third is that, other things being equal, the more suint there is in wool, the greater will be the increase in weight when stored in the East. A fourth is that in the Mountain States, in the summer when the days are hot and dry and the nights cool, wool spread out in thin layers exposed to the air may weigh several pounds more to the hundred in the early morning than in the mid-afternoon. A fifth is that sacked or baled wool, especially when stored in large piles in closed warehouses, changes its moisture content very slowly, and if it is desired to hasten this process, the wool should be spread out and the packages opened and handled in a place where there is a free circulation of air.

[1] *Jour. Soc. Chem. Ind.*, 1909, p. 1020.

of glycerol, after which treatment the wool may be exposed to a temperature of 140° C. without being affected. The explanation of this action is no doubt to be found in the fact that glycerol holds water with considerable energy, and even at these elevated temperatures all of the moisture originally present in the wool is not driven out of the fiber. In order to economise time, it is sometimes necessary to dry wool rather quickly by the use of suitable machinery and high temperatures. Where a proper regulation of the temperature is possible, the wet wool may be subjected to quite a high degree of heat without injury, for the fiber itself does not become heated up, due to the rapid evaporation of the moisture. As the fiber becomes drier, however, it is important that the temperature fall, so that at the end of the operation, when the wool has become dried to its normal content of moisture, the temperature should be that of the atmosphere.

13. Effect of Moisture on Properties of Wool.—Too much importance cannot be attached to the proper drying of wool in all of its stages of manufacture, either in scouring, dyeing, washing, or finishing. If wool is overdried; that is, if the moisture in it is reduced to an amount much less than that which it would normally contain, inferior goods will always be the result, for the intrinsic good qualities of the fiber become greatly depreciated every time such a mistake is committed.

Notwithstanding the rather popular idea that the strength of woolen goods increases with hygroscopic moisture, the very opposite is the case. Barker states [1] that the drier the wool the stronger it is. Woodmansey [2] shows that when moisture is driven off the strength of woolen fabrics is considerably increased, but the increase disappears on exposure to the air. The effect of very prolonged drying is usually to give an increase of strength to the wool which lasts at least several days. Woodmansey tested pieces dried at 100° C. and cooled in a desiccator, and then exposed to the air, as follows:

	Average Strength of 5 (3″) Warp Strips in Pounds,	Average Elongation before Rupture, Inches.	Moisture Content, Percent.
Direct from desiccator	188.4	1.225	Dry
After 5 minutes	185.8	1.525	3.0
After 15 minutes	172.4	1.800	5.5
After 30 minutes	161.0	1.875	7.5
After 60 minutes	158.4	2.150	8.7

[1] *Jour. Soc. Dyers & Col.*, 1905, p. 36.
[2] *Jour. Soc. Dyers & Col.*, 1918, p. 227.

A continuation of these figures was made possible by wetting the cloth and then allowing it to dry in the air.

	Average Strength of 5 (3″) Warp Strips in Pounds.	Average Elongation before Rupture, Inches.	Moisture Content, Percent.
Before treatment	160.0	2.26	10.04
After wetting	130.7	4.53	53.0
Damp	123.6	4.46	33.0
Air-dry	156.3	2.67	10.54

The following table shows the percentage of moisture in air-dried wool and when exposed to an atmosphere saturated with moisture,[1] as compared with the same values for other fibers:

Fiber.	Air-dry.	Saturated.	Fiber.	Air-dry.	Saturated.
Wool	8–14	30	Manila hemp	8–12	40
Silk	10–12	30	Jute	6	23
Cotton	6–8	21	Flax	5–8	13
Ramie	6–8	18			

The influence of moisture in yarns on their weaving qualities[2] is an interesting factor. Excess of moisture over the normal amount appears to decrease somewhat the tensile strength of worsted yarns, while it increases considerably the elasticity. With cotton, the result is different; the elasticity alters but very slightly and the strength increases a little. Silk appears to follow the same variations as wool.

Variation in the moisture in yarns due to variations in the relative atmospheric humidity also has a very appreciable influence on the tensile strength and count (or size) of such yarns. W. S. Lewis (*National Bureau of Standards*) has made a detailed study of these effects, and points out their influence on the testing of worsted yarns. The results show that with common changes in atmospheric conditions, worsted yarns may

[1] Kimura (*Chem. Zentralbl.*, 1922, p. 1023) has found that in an atmosphere saturated with moisture wool absorbs 28.2 to 28.7 percent of moisture, cotton 19.8 to 20.0 percent, linen 20.2 to 20.5 percent, pine wood 22 to 24 percent and paper 15.6 to 24.9 percent. When exposed to the action of gaseous ammonia wood retains 50 percent, paper and wool 4 percent, and cotton and linen 0.4 percent.

[2] Barker, *Jour. Soc. Dyers & Col.*, 1905, p. 36.

increase or decrease as much as 18 to 22 percent in tensile strength, $1\frac{1}{2}$ to 3 in yarn count and from 250 to 1700 yds. per pound. In view of these marked variations in the count, yardage and tensile strength of worsted yarns due to the influence of moisture, it is advisable to adopt some standard conditions of temperature and relative humidity in the physical testing of textile materials, in order that different tests may be of a strictly comparable nature. The atmospheric conditions recommended are 65 percent relative humidity at a temperature of 70° F.

The following table shows the influence of different relative humidities on the tensile strength of worsted yarns, being a mean of a large number of tests of different sizes of yarns:

Percent Relative Humidity at 70° F.	Tensile Strength in Grams.
45	234
55	231
65	220
75	216
85	191

The following tables show the influence of humidity on the count and yardage of worsted yarns:

	Samples.							
	Singles.						Two-ply.	
	1	2	3	4	5	6	7	8
Yarn count at 45% rel. hum.	20.25	24.58	25.51	34.49	35.47	39.09	27.74	34.28
" " " 65% rel. hum.	19.77	23.97	24.94	33.68	34.71	38.08	27.18	33.66
" " " 85% rel. hum.	18.82	22.79	23.80	31.77	32.85	36.03	25.68	31.80
Diff. in count 45% and 65%.	0.48	0.61	0.57	0.81	0.76	1.01	0.56	0.62
" " " 65% and 85%.	0.95	1.18	1.14	1.91	1.86	2.05	1.50	1.86
" " " 45% and 85%.	1.43	1.79	1.71	2.72	2.62	3.06	2.06	2.48
Diff. yards per pound:								
45% and 65%	269	342	319	454	426	566	314	347
65% and 85%	532	661	638	1070	1042	1148	840	1042
45% and 85%	801	1002	958	1523	1467	1714	1154	1389

Scheurer[1] experimented with wool and other fibers with respect to the amount of moisture which would be absorbed at 100° C. in an atmosphere

[1] *Bull. Soc. Ind. Mulh.*, 1900.

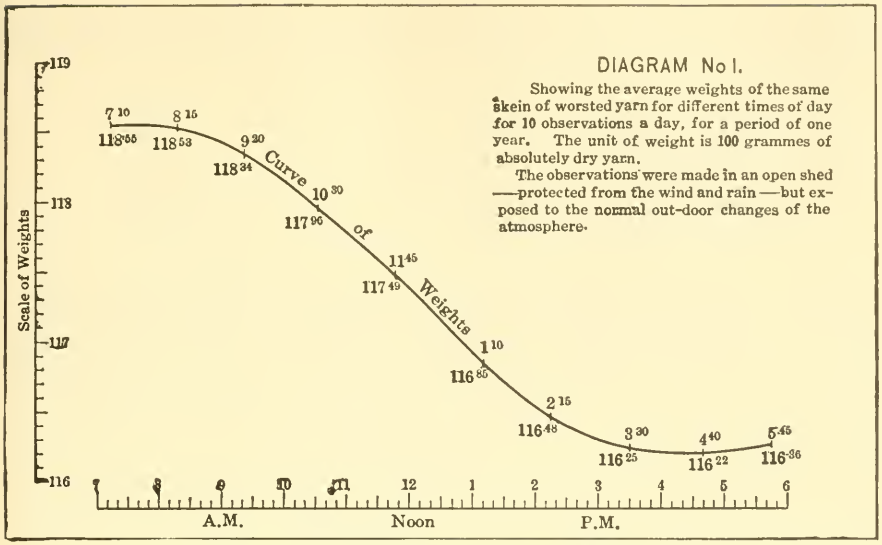


FIG. 73.—Effect of Moisture Content on Worsted Yarn.

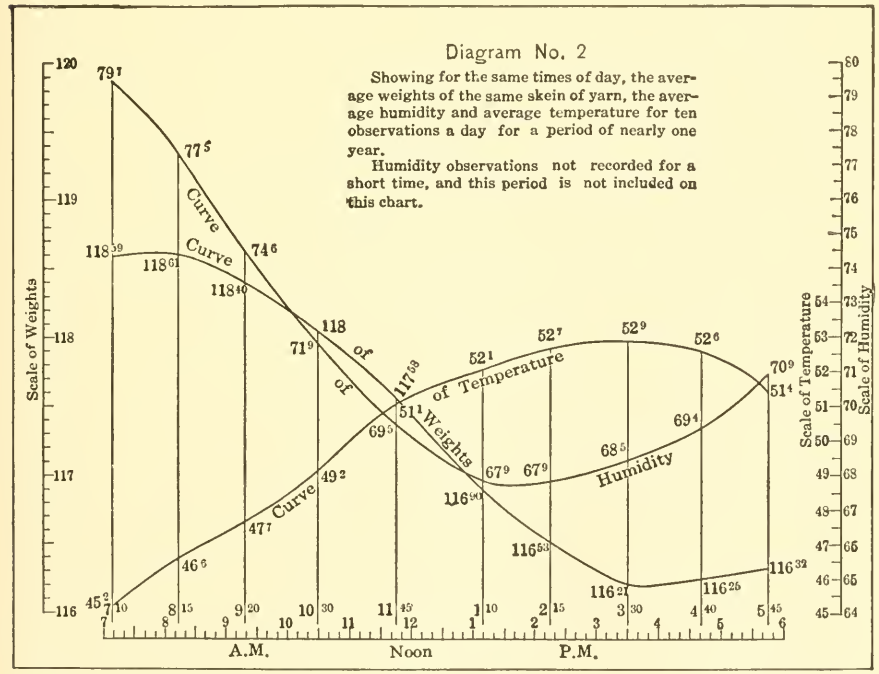


FIG. 74 —Variations in Physical Properties of Wool Due to Hygroscopic Moisture.

saturated with steam. His results were as follows: 100 grams each of the several fibers dried at 100° C. fixed the following amounts of water:

	Percent.
Bleached cotton	23.0
Unbleached linen	27.7
Unbleached jute	28.4
Bleached silk	36.5
Bleached and mordanted wool	50.0

An interesting study of the variations in the content of the hydroscopic moisture in wool has been made by W. D. Hartshorne of the Arlington Mills. He exposed a skein of worsted yarn for a year to the varying conditions of moisture in one place and took regular weighings throughout stated times of the day. The average results are shown in the accompanying diagram (see Fig. 73). The second diagram (see Fig. 74) shows the curves representing the relative variations in the weight, temperature, and humidity, showing the natural composite effect of these two factors on the amount of hygroscopic moisture in the wool.

CHAPTER VI

ACTION OF CHEMICAL AGENTS ON WOOL

1. Action of Heat.—When wool is heated for some time in a dry atmosphere to 212° to 220° F. (100° to 105° C.) it loses its total hygroscopic moisture and the fiber becomes harsh, rough, and brittle, and loses much of its tensile strength. If left in the air, however, it rapidly absorbs moisture again and regains some, but not all, of its former softness and strength. Consequently the lower the temperature employed in the drying of woolen goods the more beneficial it will be in preserving the original good properties of the fiber.

When wool is heated in a moist atmosphere to 212° F. (steam or boiling water) the fiber becomes quite plastic, and the form to which it is shaped under these conditions it will retain if later cooled. This property is the basis of the important finishing processes of wet and dry decatising, crabbing and pressing of woolen fabrics, the shaping of hat felts, etc.

If maintained for any length of time at temperatures much above 100° C. (especially if dry heat) the wool fiber will show evidence of chemical decomposition (by discoloration and great loss of strength). At 130° C. decomposition becomes quite rapid, the wool acquires a yellow color, and ammonia is evolved. At 140° to 150° C. the evolution of gases containing sulfur is also to be noticed.

When subjected to dry distillation wool evolves abundant gases containing sulfur, also much ammonium carbonate and pyridine bases, leaving behind a voluminous residue of coke which is very difficult to ignite to a complete ash.

When heated in the air in a Bunsen flame the wool fiber burns slowly and with some difficulty, developing a peculiar and rather unpleasant odor (empyreumatic) closely resembling that of burning feathers or horn. The fiber seems at first to melt in the flame so that the burnt end exhibits a fused globular mass of coke.

2. Reactions with Water and Steam.—Though wool is insoluble in cold water and also in hot water under ordinary conditions, still the continued action of boiling water appears to decompose the wool fiber to a certain extent, as both ammonia and hydrogen sulfide may be detected in the gases evolved. The soluble decomposition products of wool produced by boiling with water show all the characteristic properties of the peptones.

Suida suggests that this action of boiling water on wool may account for the lack of fastness to rubbing often noticed with basic colors on wool.

By heating wool to a temperature of 130° C. with water under pressure, the fiber appears to become completely disorganised, and on drying may be rubbed into a fine powder. At higher temperatures the fiber is completely dissolved. Based on this fact, Knecht has proposed a method for the " carbonisation " of mixed woolen and silk goods, for the purpose of recovering the silk, as the latter is not materially affected by this treatment. Though theoretically possible, this method does not appear to have any practical value.

Gardner and Kastner have shown that on long boiling in water a small quantity of the wool fiber is dissolved, and to this soluble portion they have given the name of *wool gelatine;* it amounts to about 1.65 percent of the weight of the wool. Gardner claims that this substance plays an important rôle in the mordanting of wool with chrome. Gelmo and Suida [1] claim that a partial hydration of the wool takes place on prolonged boiling in water or more particularly in dilute acids.

Hertz and Barraclough [2] point out that wool on boiling in water yields a soluble substance which gives the tannin and biuret reactions for gelatine. Solutions of lead acetate, however, precipitate wool gelatine from solution, but have no effect on solutions of ordinary glue or gelatine. Further experiments seem to indicate that wool gelatine consists of three substances: (1) One which is not precipitated by Night Blue, but which is precipitated by the tannin-salt reagent (a filtered mixture of 100 cc. of a 2 percent solution of tannin and 100 cc. of a saturated solution of salt); (2) one which is precipitated by Night Blue, and which goes into solution when this precipitate is decomposed with barium hydrate, and after removal of excess of barium hydrate is again capable of precipitation by either Night Blue or tannin-salt; (3) one which is precipitated by Night Blue, but on decomposing the precipitate with barium hydrate, remains insoluble.

When wool undergoes a partial hydrolysis by the prolonged action of boiling water (or dilute acid solutions) in the various operations of washing, dyeing, mordanting, and finishing, so that the fiber suffers material loss in strength or elasticity, it is spoken of as " burnt."

To indicate the degree to which wool is attacked—that is, hydrolysed or dissolved by the various reagents employed in mordanting, dyeing and carbonising and similar operations, use has been made of the so-called biuret reaction.[3] As standard, there is prepared a colorimetric scale by dissolving 1 gram of wool yarn in caustic soda, neutralising with hydrochloric acid,

[1] *Färber-Zeit.*, 1905, pp. 295 and 314.
[2] *Jour. Soc. Dyers & Col.*, 1909, p. 274.
[3] Gelmo and Suida, *Ber. Akad. Wissensch. Wien.*, 1905.

boiling to expel free hydrogen sulfide and adding a definite quantity of normal caustic soda and twentieth-normal copper sulfate to progressive quantities of the wool solution. After standing one hour eleven violet-colored solutions of increasing depth of tint corresponding to a content of 0 to 0.01 gram of dissolved wool are obtained. These standards are easily distinguishable and comparable, as regards the extent of decomposition of the fiber with the various liquors in which the wool has been treated in the course of any of the operations mentioned above. It was found that neutral soap had practically no dissolving effect on the wool fiber, whereas caustic alkali and alkali carbonates dissolve the fiber in amounts roughly proportional to their concentration, the destructive action increasing markedly with rise of temperature. In mordanting with bichromate it was found that the use of bichromate alone, or of equal parts of bichromate and oxalic acid, was considerably more destructive than bichromate used in conjunction with lactic acid, sulfuric acid, cream of tartar, or formic acid. Wool that had been carbonised—that is, impregnated with 4 percent sulfuric acid solution and dried at 80° C. was found to lose three to four times the weight of fiber as compared with uncarbonised wool, when the two were subjected to similar subsequent treatment with dilute sulfuric acid and sodium sulfate. When wool is heated in a bath of stannous chloride slightly acidified with acetic acid it retains its natural color; on the other hand, when wool has been acted on by an alkali a portion of its sulfur was dissolved in the form of alkali sulfide, and a portion was retained in the fiber in the form of an insoluble compounds of a sulfide nature. The latter when such wool was treated with stannous chloride, as above, gives rise to a brown coloration owing to the formation of stannous sulfide, and the depth of this coloration is a rough index to the extent of the decomposition that has been brought about by the destructive action of the alkali on the wool.[1]

When wool is subjected to the action of steam at 100° C. it is much more rapidly attacked than cotton. According to Scheurer[2] after three hours' treatment with steam the wool loses 18 percent in strength, after six hours, 23 percent, after sixty hours, 75 percent; whereas the latter figure was only reached by cotton after a treatment lasting four hundred and twenty hours.

Scheurer[3] has made some tests on the effect of steaming on woolen cloth; a good quality of unbleached cashmere cloth, which had been previously washed with a lukewarm solution of soap and soda, was passed through weak oxalic acid and then washed again. The steaming was carried out at a temperature of 99° to 100° C. for varying periods of time

[1] Becke, *Färber-Zeit.*, 1912, pp. 15 and 66.
[2] *Färber-Zeit.*, 1893, p. 290.
[3] *Bull. Soc. Ind. Mulh.*, 1893.

and the results as to tensile strength are shown in the following table:

	Warp.	Filling.	Mean.
Original cloth	100	100	100
Steamed 3 hours	86	78	82
" 6 "	80	75	77
" 12 "	75	69	72
" 24 "	68	53	60
" 36 "	62	37	50
" 48 "	40	32	36
" 60 "	29	23	26

Woodmansey[1] has shown that wool loses much in strength when boiled in water, but much of this strength returns on drying again. Woodmansey obtained the following results on the strength of strips of woolen cloth:

	Strength in Pounds.
Untreated	145.0
Soaked 1 hour in water:	
Tested wet	104.3
Air-dried 3 days	140.3
Boiled 1 hour in water:	
Tested wet	83.6
Air-dried 3 days	128.3

Dry heat is not as destructive to wool as moist heat, for whereas a temperature of 130° C. moist heat under pressure will completely disintegrate wool, a much higher degree of heat will only reduce the strength slightly in the absence of water. Woodmansey gives results as follows:

	Strength in Pounds.
Unheated wool	145
Heated gradually to 150° C.	141
Heated gradually to 200° C.	135

Steaming wool at high temperatures also has the effect of increasing its affinity for dyestuffs. Thus in the process of crabbing, where the woolen pieces are wound under high tension through boiling water on to a hollow perforated cylinder and then subjected to the action of high-pressure steam, the end which is nearer the roller will dye a deeper shade than the

[1] *Jour. Soc. Dyers & Col.*, 1918, p. 228.

outer portions. To avoid this defect it is usually necessary to crab twice and reverse the ends.

The action of water and of hot moisture on wool is of importance in the processes technically employed for the shrinking of woolen fabrics. There are two general processes in vogue, the " London " shrunk and the " steam " shrunk. The former is the most satisfactory and the process is carried out by wrapping the cloth, along with a leader cloth, on a roller. The leader has previously been run through a tub of cold water and thoroughly saturated or wet out. Rolling the two pieces of cloth together causes the wet leader and the dry cloth to be shrunk to form alternate layers, and the dry cloth absorbs the moisture from the wet one. Great care must be taken to have the cloth rolled perfectly even. After rolling it is put aside for some time until the dry cloth has properly absorbed the moisture, and this will vary with the weight and structure of the goods. The cloth is then unrolled and hung on bars in a cool room in which the air is circulated, and the goods are slowly dried to obtain the maximum amount of shrinkage. After drying, the cloth is pressed in hydraulic plate presses and should not be pressed over rollers. The London process if properly executed will not injure the most delicate fabrics nor will it start the colors. The method of steam shrinking is quicker and cheaper, but it is liable to injure the goods and to start the colors bleeding. The cloth is put on a steam-blowing machine and thoroughly impregnated with steam. The goods are then allowed to cool off and to dry naturally, after which they are finished in a hydraulic press. The steam process also affects the handle or feel of the cloth, but it shrinks the fabric quickly and effectively.

After a series of carefully planned experiments, Justin-Mueller [1] comes to the conclusion that it is possible to felt wool by heating in a bath of distilled water without agitation and at a temperature slightly below the boiling point. The felting action may be increased by the addition of acids and will increase in proportion to the quantity of acid used. The felting action is also more apparent when lime-water is used than when distilled water is employed. It is claimed that the addition of acid and continued boiling brings the fiber into the condition of a " gel " so that the fibers become cemented together.

3. Acid and Basic Nature of Wool.—In its chemical reactions wool appears to exhibit the characteristics both of an acid and a base, and no doubt it contains an amino acid in its composition. The presence of an amino group is evidenced by the formation of ammonia as one of the decomposition products of wool, also by the strong affinity of wool for the acid dyestuffs, or even by its ability to combine with acids in general.

The acid nature of wool accounts for the possibility of the formation

[1] *Zeit. Farb. Ind.*, vol. 8, p. 90.

of compounds of the fiber with various metallic salts, alkalies, and metallic oxides, and therefore for the difference in behavior in dyeing between wools which have been scoured with alkaline carbonates or treated with metallic salts or hard water, and wool which has not had its acid groups saturated in this way. It also accounts for the fact that different wools require the addition of different amounts of acid to the dye-bath to give the same effect.[1]

The coefficient of acidity, which is a figure meaning the number of milligrams of caustic potash neutralised by one gram of substance, has been determined for wool, together with a number of other albuminoids, as follows:

Wool	57.0	Albumen	20.9
Silk	143.0	Gelatine	28.4
		Globulin	101.5

Although the amount of alkali absorbed and neutralised by wool may be thus quantitatively determined, the amount of acid absorbed cannot be so obtained, as wool, though it absorbs acids, apparently does not neutralise them.

Wool which has been treated with a dilute solution of caustic alkali apparently shows no difference from untreated wool in its dyeing properties with respect to acid and basic dyes. That alkali has been absorbed by the wool, however, is shown by the fact that it has an increased attraction for such dyes as Benzopurpurine, etc., which only dye wool from a slightly alkaline bath.

By treatment with concentrated solutions of caustic soda (80° Tw.). Wool absorbs about 50 percent of its weight of sodium hydrate from solution. Nor can this alkali be totally removed from the wool by subsequent washing with water alone, but requires a treatment with acid for complete neutralisation. Wool so treated exhibits a lessened affinity for basic dyes, showing a probable neutralisation to a greater or lesser extent of its acid component.

In a study of the hydrolytic processes which take place in the dyeing of wool, Suida[2] states that the keratine of wool is an albuminoid that readily undergoes hydrolysis whereby the wool becomes amphoteric (i.e., exhibiting the qualities of both an acid and a base). During the first period of hydrolysis there is a rapid increase in acid properties, but these then diminish and the basic properties are retained to the end because the final products contain either guanidyl or imidazole groups. It seems probable that in dyeing or mordanting, the acid or base combines directly with the basic or acid group of the wool to form an

[1] See experiments of Gelmo and Suida, *Ber. Akad. Wissenschaften*, May, 1905.

[2] *Zeit. angew. Chem.*, 1909, p. 2131.

insoluble salt. Wool is not dyed appreciably when it is treated in a neutral bath with the sodium salt of a dye acid because the acid groups of wool are not able to decompose the more stable salt. Wool, however, is dyed by an aqueous solution of an acid dye, and in this case the basic groups of the wool unite directly with the acid dye to form an insoluble salt. Wool is dyed intensively when treated with the hydrochloride of a basic dye; in this case the hydrochloric acid of the dye salt probably combines with basic groups of the wool and the dye itself combines with acid groups; although it must be remembered that a hydrolysis of the wool is taking place, and therefore quite an appreciable quantity of it passes into solution and unites with the hydrochloric acid of the dye salt. This accounts for the fact that all of the chlorine is found in the dyebath, which also gives the biuret reaction very readily. Wool is also dyed on being treated in an acid bath with the sodium salt of a dye acid or with the dye acid itself. The acid in the bath aids the hydrolysis of the wool, and combines with one of its cleavage products, while the acid dye combines with basic groups of the wool. On the other hand, wool is not dyed in an acid solution of a salt of a basic dye, for in this case the dye base is not set free and cannot combine with the acid groups of the wool. Since in the hydrolysis of wool the basic groups eventually become more prominent it is easy to understand that acid dyes act longer upon wool and produce more solid colors.

Becke [1] states that the stannous chloride reaction gives only partial information concerning the injury done to wool fibers by alkaline solutions. The biuret reaction, however, he says, yields accurate numerical data on the quantity of wool substance dissolved by acids, alkalies, soaps and such like. There is a close relation between the loss by solution of wool substance thus determined and the tensile strength and elasticity of the wool yarn. In this connection it appears that sulfuric acid has a marked hydrolysing action on wool. The basic substances formed dissolve in the acid solution, while the acid products are dissolved readily by subsequent alkaline treatment. Becke also states that, contrary to the prevailing opinion that dyeing in acid baths is least injurious to wool, dyeing with sulfuric acid and glaubersalt or with sodium bisulfate is quite harmful, as it renders the wool susceptible to attack by subsequent treatment with water, soap, soda ash or other alkalies. Becke's opinions in this matter, however, need to be further confirmed by exact tests before they can be accepted.

Vignon [2] has experimented on the amount of heat disengaged by treating wool with different acids and alkalies, with the following results, using 100 grams of unbleached wool:

[1] *Färber Zeitung*, vol. 30, p. 128.
[2] *Compt. rend.*, 1890, No. 17.

Reagent.	Calories Liberated.
Potassium hydrate (normal)	24.50
Sodium hydrate (normal)	24.30
Hydrochloric acid (normal)	20.05
Sulfuric acid (normal)	20.90

These figures are interesting in indicating the relative acidity and alkalinity of the wool fiber.

4. Action of Acids on Wool.—When treated with **dilute acids,** the wool fiber does not appear to undergo any appreciable change; although, from the fact that acids are very readily absorbed by wool and very tenaciously held by it, there is reason to believe that some chemical combination takes place between the fiber and the acid. It can be shown, for example, that if wool be treated with **dilute sulfuric acid,** all of the acid cannot again be extracted by boiling in water until the washwaters are perfectly neutral; and wool thus prepared has the power of combining with the various acid colors without the necessity of adding any acid to the dye-bath. Fort and Lloyd [1] came to the conclusion that some acid was retained permanently by the wool fiber even under continued extraction with boiling water. Harrison,[2] however, from experiments in which twenty-four consecutive washings were used, came to the conclusion that all of the acid could be removed by simply washing and consequently there was no evidence of any chemical combination between the fiber and the acid. The following table shows the relative absorption of sulfuric acid from its solutions by wool (Mills and Takamine):

Percent Acid Used.	Percent Left in Solution.	Percent Absorbed by Wool.
$2\frac{1}{2}$	0.38	2.12
5	2.17	2.83
10	6.37	3.63
20	15.87	4.13
40	35.18	4.82

Mills and Takamine also give the equivalent absorption of wool and silk for different acids and ammonia, as follows:

	Sulfuric Acid.	Hydrochloric Acid.	Ammonia.
Wool	2.2	2.0	1.0
Silk	2.0	1.0	6.4

Silk, therefore is more acid in character than wool.

[1] *Jour. Soc. Dyers & Col.*, 1914, p. 5.

[2] *Jour. Soc. Dyers & Col.*, 1917, p. 57.

Wool that has been treated with warm dilute solutions of sulfuric acid not only shows an increased affinity for acid colors, but also a decreased affinity for basic colors. Alcoholic solutions of sulfuric acid appear to act more effectively in this respect than the aqueous solution. According to Gillet [1] the acid which is fixed in wool may be removed by treatment with a dilute solution of soda ash and the wool will then regain its original dyeing properties. Gelmo and Suida confirm this but use ammonium carbonate. Acidified wool also shows an increased power of dyeing alizarine colors direct.

Other acids have about the same effect on wool as sulfuric acid, only in the case of acetic acid it is necessary to add the acid directly to the dye bath in order to hinder the fixation of basic colors or increase the absorption of acid colors.[2] It is also true that if wool which has been treated with sulfuric acid is boiled in water, ammonium sulfate is to be found in the solution, showing that some chemical action has probably taken place between the acid and some basic constituent of the wool fiber.

Hydrochloric acid acts much in the same manner as sulfuric acid, although the amount permanently absorbed by the fiber is quite small, most of the acid being removed by boiling water.

Mills and Takamine [1] have studied the relative absorption of mixed acids on the fibers, as follows:

Ratio.	Wool.		Silk.	
H_2SO_4 : HCl.	H_2SO_4.	HCl.	H_2SO_4.	HCl.
1 : 1	5.0	32.5	6.6	0.87
1 : 2	11.3	25.5	5.0	2.5
1 : 4	16.6	18.4	4.0	3.5

The rate of absorption of these acids when present in the ratio of H_2SO_4 : 4HCl was as follows:

Fiber.	H_2SO_4.	HCl.
Wool	100	179.6
Silk	100	175.0

[1] *Rev. Gen. Mat. Col.*, 1899, p. 157.
[2] See Gelmo and Suida, *Ber. Akad. Wissenschaften*, May, 1905.
[1] *Jour. Chem. Soc.*, 1883, p. 144.

The maximum absorption for silk and cotton was:

Reagent.	Cotton.	Silk.
H_2SO_4	1	2.6
HCl	1	2.2
NaOH	1	2.2

When wool is treated with weak reagents separately in the proportion HCl : NaOH, the absorption is in the ratio 2HCl : 3NaOH. With silk and cotton the ratio is 3HCl : 10NaOH.

Chromic acid is absorbed in like manner, and no doubt the usefulness of bichromates as mordants for wool depends somewhat on the chemical combination between the fiber and the chromic acid.

With **nitric acid** wool behaves somewhat differently, for unless the acid be very dilute and the temperature low, the fiber will assume a yellow color, which is probably due to the formation of xanthoproteic acid. Formerly this yellow color was supposed to be due to the formation of picric acid, but this view is erroneous. Nitric acid has a similar effect on the skin, the yellow stains which it produces being a subject of common experience. If the strength of the acid is below 4° Tw., the yellow coloration on wool is not very marked, and in this manner nitric acid has been largely employed as a stripping agent, especially for shoddies.

When treated by the prolonged action of boiling dilute acids, wool undergoes some decomposition which may be carried out to complete solution of the fiber when boiled under pressure, as, for instance, by heating with dilute hydrochloric acid (1:5) to 190° C.

Georgievics and Pollak have recently brought out some work in regard to the study of the absorption of acid by wool. It seems that the absorption of acid by the wool fiber is shown to be a natural adsorption process. With the acid used adsorption is found to proceed irregularly in the case of the weaker solutions, but with solutions containing 0.5 gram of acid and upward in 250 c.c. of water, the adsorption can be expressed by formulas, and diagrams of curves are given in illustration. Ignoring the results obtained with the weaker solution, and taking molecular proportions of the acid, the order of adsorption was found to be as follows: Nitric, hydrochloric, oxalic, sulfuric, formic, succinic, adipic and acetic. Nitric acid was the most adsorbed and acetic acid the least. Mineral acids are in general adsorbed to a greater extent than fatty acids, but the reverse is the case when charcoal is the absorbent material. It was found that as the strength of the acid solution increased the relative amount taken up by the wool decreased, and in every case, above a certain concen-

tration (about 0.5 gram of acid per 250 cc. of solution) the distribution of the acid between the fiber and the solution follows the general formula:

$$\frac{\sqrt[x]{C_s}}{C_f} = K,$$

where C_s and C_f represent the quantity of acid in grams in the solution and fiber respectively, and x and K are constants which are different for the different acids. For hydrochloric acid $x = 5$ and $K = 0.293$, while for acetic acid the values are $x = 1.75$ and $K = 0.545$. A formula of this type is characteristic of all adsorption phenomena. Further experiments on this subject by Georgievics, however, show that in the case of very dilute solutions the taking up of the acid by the wool is a solution phenomenon and not one of adsorption; but in the case of stronger solutions the solution factor is overshadowed by that of adsorption.

The present results agree with those obtained formerly by Walker and Appleyard on the adsorption of acid by silk. No relation could be found between the adsorption of an acid and the degree of dissociation of its solution. The adsorption of acid by wool was found to be but little dependent on the temperature. Usually a little less was adsorbed at the higher temperatures. The adsorption of an acid is decidedly affected by the presence of another acid, and in varying ways. For example, the adsorption of sulfuric acid from very dilute solutions is slightly increased, but decidedly diminished in stronger solutions, by the presence of hydrochloric acid, while the adsorption of hydrochloric acid from all concentrations is lessened by the presence of sulfuric acid. The adsorption of acid by wool from a solution of a mixture of acid is less than from an equivalent quantity of a single acid. This excludes the possibility of a simple salt formation between the fiber substance and the acid.

Fort and Lloyd [1] have also studied the adsorption of acids by wool. A comparative series of experiments was made, giving a range of treatments from 1 to 12 percent of acid, and using hydrochloric, sulfuric, oxalic, formic and acetic acids. The results of the acid absorbed and that permanently retained after a series of washings with hot water are shown in the table on page 150.

If curves are drawn representing these results there will be found distinct nodes where a higher amount of acid is used and yet the amounts absorbed and permanently retained by the fiber are actually less. It is probable that at these points the wool is undergoing changes by hydrolysis, and the hydrolysed wool products are combining with the acid.

Richards [2] has shown that by the action of nitrous acid, wool is diazotised in a manner similar to an amino compound, and may be developed

[1] *Jour. Soc. Dyers & Col.*, 1914, p. 5.
[2] *Jour. Soc. Chem. Ind.*, 1888, p. 841.

Percent Acid Used.	Hydrochloric Acid.		Sulfuric Acid.		Oxalic Acid.		Acetic Acid.		Formic Acid.	
	Absorbed, Percent.	Permanently Retained, Percent.	Absorbed, Percent.	Permanently Retained, Percent.	Absorbed, Percent.	Permanently Retained, Percent.	Absorbed, Percent.	Permanently Retained, Percent.	Absorbed, Percent.	Permanently Retained, Percent.
1	0.97	0.63	0.97	0.78	0.94	0.72	0.73	0.63	0.33	0.15
2	1.51	0.58	1.90	1.48	1.72	0.95	0.94	0.73	0.71	0.34
3	1.97	0.71	2.67	1.76	2.46	0.94	0.97	0.72	0.95	0.54
4	2.32	0.78	3.58	2.12	3.16	1.33	0.35	1.06	1.35	0.83
5	2.25	0.61	3.48	1.97	3.62	1.51	1.27	0.91	1.51	0.86
6	2.40	0.72	3.86	1.90	4.06	1.31	1.19	0.83	1.78	1.16
7	2.47	0.63	3.72	2.09	4.67	1.53	1.09	0.68	1.58	0.64
8	2.71	0.76	3.80	2.04	5.16	1.78	1.25	0.70	1.55	0.65
9	2.40	0.51	3.62	1.92	5.03	1.53	1.30	0.68	1.71	0.71
10	2.58	0.61	3.79	2.00	5.16	1.39	1.39	0.73	1.48	0.55
11	2.81	0.74	4.17	2.23	5.61	1.71	1.41	0.78	1.81	0.65
12	2.69	0.61	4.06	2.03	5.77	1.47	1.40	0.64	1.54	0.56

subsequently in an alkaline solution of a phenol, giving rise to quite a variety of shades. According to Prud'homme [1] instead of a diazo body there is formed a nitrosamine, and he cites the behavior of wool with formaldehyde and with sulfurous acid to show the absence of an animo compound. Flick agrees with this view while Grandmougin and Bourry object to the proof of Prud'homme as being only a negative indication and leaving the question as to the existence of an amino or an imino group still an open one. According to Emil Fischer a diazotisation of wool is not regarded as possible.[2]

When wool is treated in the dark with an acid solution of sodium nitrite (6 percent) it quickly acquires a pale-yellow color, rapidly changing on exposure to light. Wool prepared in this manner is turned brown by boiling water, and caustic soda effects the same change, the color becoming yellow again on treatment with acids. Stannous chloride in a warm solution discharges the brown color. Diazotised wool appears to have an increased attraction for basic dyes and a lessened affinity for the acid dyes. Exposure to light bleaches diazotised wool, which is then turned orange by alkalies, and not brown. The following colors may be obtained by treating diazotised wool with various phenols in alkaline solution:

Phenol.	Color.	Reaction with H_2SO_4.
Resorcin	Orange	Pale red
Orcin	Orange	Pale red
Pyrogallol	Yellowish brown	Orange
Phloroglucol	Bordeaux	No change
Alpha-naphthol	Red	Black
Beta-naphthol	Red	Pale red

[1] *Färb. Zeit.*, 1898, p. 346.

[2] See also Brandt, *Färb. Zeit.*, 1901, p. 238; Kayser, *Zeit. Farb., Ind.*, 1903, p. 80; and Justin Mueller, *Rev. Gen. Mat. Col.*, 1902, p. 67, on this subject.

When dyed in connection with metallic mordants, these phenol colors are fast to light, fulling, acids, and boiling water. Tin mordants give yellow and orange shades; aluminium, orange; iron, dark browns and olive browns; chromium and copper, garnet. Wool treated with nitrous acid acquires a harsh feel and is non-hygroscopic. It also appears to have an increased affinity for basic dyes.[1]

The acid number of diazotised wool is 169, and its iodine number 4.7, whereas untreated wool has the numbers 88 and 18.4, respectively. Diazotised wool also appears to contain less nitrogen than ordinary wool.[2]

In common with most other organic substances, wool is totally destroyed by the action of **concentrated mineral acids.** On treatment with cold concentrated sulfuric acid for a short time wool is not seriously disintegrated; the fiber, however, suffers a change in that it loses all affinity for acid dyes, while it strongly attracts basic dyes.

This reaction does not seem to have met with any commercial application,[3] as it would have to be operated with extreme care to avoid weakening and injury to the wool. The acid used in the Badische patent is 60° to 62° Bé. Becke and Beil (*Ger. Pat.* 168,026) by using a stronger acid ($98\frac{1}{2}$ per cent H_2SO_4) obtain better effects and at the same time avoid the danger of injuring the wool. Instead of washing the treated wool directly with water (which results in strong heating and tendering of the fiber) it is washed first in a diluted, and if necessary cooled, sulfuric acid. The first wash is with 95 percent acid, the second with 90 percent acid, and so on till the tenth bath is of 10 percent acid, and the eleventh bath is pure water. Such a process, however, would hardly be of any practical value.

Knecht has found that by boiling wool with moderately concentrated sulfuric acid (2 parts sulfuric acid to 3 parts water) the fiber is dissolved with the formation of lanuginic acid and other amino bodies as well as ammonia and sulfuretted hydrogen. Other mineral and organic acids have the same effect.

Grandmougin [4] calls attention to the fact that this effect of concentrated sulfuric acid is shared by many other chemicals, such as caustic soda, phosphoric acid, nitric acid followed by tin chloride, zinc chloride, calcium chloride, sulfocyanides, bisulfites, hydrosulfites, resorcinol, tartaric acid, and citric acid. All of these in concentrated solutions, either cold or by steaming, effect the affinity of wool for acid dyes, and also may be used for the production of crêpe effects in printing.

With **organic acids,** wool is usually reactive, readily absorbing oxalic, lactic, tartaric, acetic, etc., acids. **Tannic acid,** however, is an exception,

[1] *Bull. Soc. Ind. Mulh.*, 1899, p. 221.
[2] Lidow, *Chem. Centr.*, 1901, p. 703.
[3] See Badische Co., *Fr. Pat.* 318,741.
[4] *Zeit. Farb. Ind.*, 1906, p. 223.

and is not absorbed to any extent by the fiber. But if wool is treated in a boiling solution of tannic acid and the latter fixed in the fiber by a subsequent treatment in a solution of tartar emetic, stannous chloride, or other suitable metallic salt, it will be found that the fiber becomes altered in such manner that it no longer exhibits its normal affinity toward acid, substantive, and mordant dyes. Toward basic dyes, however, the affinity of the wool becomes considerably increased by reason of the presence of tannin.

This reaction is the basis of applying the so-called "resist" process to the dyeing of wool. Worsted or woolen yarn is treated with a solution of tannic acid, and then with one of stannous chloride. The treated yarn is then woven with untreated yarn, and the fabric dyed in the piece with various colors which have little or no affinity for the treated fiber, but show their normal dyeing properties toward the untreated wool. Such dyes are known as "resist" colors for this process. A number of one-bath or after-chromed alizarine or mordant dyes are suitable for this purpose.

This process was introduced by Beeke and Beil [1] and is also applicable to some extent to silk as well as to wool. The details of the process are given as follows (Farbw. Höchst): (1) For the preparation of a full reserve: (*a*) for acid dyes and white, treat the wool with 10 percent (on weight of the wool) of tannic acid and 4 percent of formic acid (85 percent) and 50 parts of water, boil for one hour, then cool to 160° F. and add 3 percent stannous chloride, and work for one-half hour at 160° F., then wash and dry. The treatment with stannous chloride may also be carried out in a fresh bath with the addition of 1 percent of formic acid; (*b*) for fast colors the wool may be previously dyed with vat or mordant dyes in the usual manner and then "prepared" in a fresh bath as above. For the production of uniform results the dilution of the bath must be large and the time of operation long; iron apparatus is not suitable for use, and if copper apparatus is used, an addition of 2 percent of ammonium sulfocyanide is necessary. (2) Preparation for half reserve: use a bath containing 10 percent of tannin and 4 percent of formic acid, work one hour at the boil; then without rinsing enter a second bath containing at first only water, and after standing for some time add 6 percent of tartaric acid and 5 percent of sodium acetate; work for one-half hour at 200° F., and wash.

When wool is treated with acetic anhydride in the presence of an acid catalyst, particularly sulfuric acid, it retains its physical properties but permanently resists the dyeing action of acid colors.[2]

[1] *Ger. Pat.* 137,947; see also *Zeit. Farb. Ind.*, 1906, p. 62.

[2] See Munz and Haynn, *Chem. Zeit.*, 1922, p. 895.

5. Action of Alkalies on Wool.—Although so resistant to the action of acids, on the other hand, wool is quite sensitive to alkalies (see Fig. 75); so much so, in fact, that a 5 percent solution of caustic soda at a boiling temperature will completely dissolve wool in a few minutes. From this fact it is easy to understand why soaps, and scouring and fulling agents in general, should be free from appreciable amounts of caustic alkalies. The weaker alkaline salts, such as the carbonates, soaps, etc., are not so destructive in their action, and when employed at moderate temperatures

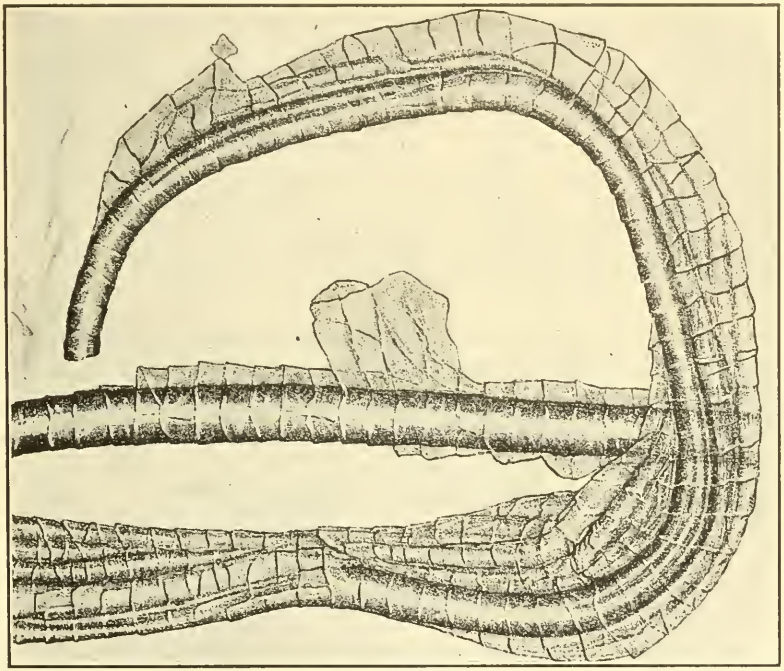


FIG. 75.—Wool Fiber Treated with Caustic Soda Solution, Showing Extreme Swelling and Gradual Decomposition.

they are not regarded as deleterious, and are largely used in scouring and fulling. With respect to the amount of caustic alkali necessary to decompose wool, Knecht found that on boiling wool for three hours with 3 percent (on the weight of the wool) of caustic soda the fiber was not disintegrated, but on increasing the amount to 6 percent complete disintegration took place and the wool was almost entirely dissolved.

The action of concentrated solutions of caustic alkalies on wool is a rather peculiar one. Solutions of caustic soda of a strength below 75° Tw. will rapidly disintegrate the fiber, but with solutions of 75°–100° Tw. the fiber is no longer disintegrated, but, on the other hand, increases from

25 to 35 percent in tensile strength, becomes quite white in appearance, and acquires a high luster and a silky scroop. The maximum effect is obtained by using a caustic soda solution of 80° Tw. and keeping the temperature below 20° C.[1] The duration of the treatment should not be more than five minutes. Buntrock shows the effect of different concentrations of caustic soda on the strength of wool as follows:

Solution.	Tensile Strength in Grams.	Solution.	Tensile Strength in Grams.
Untreated wool.....	610	NaOH of 32° Bé.....	420
NaOH of 4° Bé.....	510	" 36° Bé.....	580
" 8° Bé.....	475	" 40° Bé.....	770
" 12° Bé.....	250	" 42° Bé.....	815
" 16° Bé.....	180	" 44° Bé.....	740
" 20° Bé.....	95	" 48° Bé.....	720
" 24° Bé.....	200	" 50° Bé.....	620
" 28° Bé.....	240		

There consequently appears to be a minimum point at 20° Bé. and a maximum point at 42° Bé., although even at 50° Bé. the strength is greater than the original untreated wool. Buntrock also shows the effect of adding glycerol, using 100 parts of caustic soda solution of 20° Bé and

25 parts of glycerol gave strength of				550	grams
50	"	"	"	730	"
75	"	"	"	700	"
100	"	"	"	700	"
Without glycerol gave strength of				95	"

The addition of glycerol to the solution of caustic soda renders the action of the alkali more effective. Wool treated in this manner may be said to be "mercerised," though the action of the caustic soda in this case is not quite analogous to that in the mercerisation of cotton. From the decrease in the density of the caustic soda solutions employed, it has been shown that the wool absorbs a considerable amount of sodium hydrate from solution. Whether this alkali is held by the wool in true chemical combination has not been ascertained. The treated wool contains but a small amount of sulfur compared with that present in the original fiber; analysis, in fact, shows that only about 15 percent of the original sulfur remains in the mercerised wool. The dyeing qualities of the latter are also different from the original fiber in that it absorbs more dyestuff from solution and hence yields heavier shades. Quantita-

[1] Matthews, *Jour. Soc. Chem. Ind.*, 1902, p. 685.

tive tests have shown that the increase in the absorption of dyestuffs is as follows:

Class of Dyestuffs.	Increase, Percent.
Basic	12.5
Acid	20.0
Substantive	25.0
Mordant	33.3

Mercerised wool also shows an increased absorption with respect to solutions of various metallic salts.

Crêpon effects may be obtained on union goods (of wool and cotton yarns) by the action of strong caustic soda, which exercises a strong shrinking action on the cotton while not materially affecting the wool. A caustic soda solution of about 50° Tw. is used at a temperature under 50° F., and the time of immersion should not be more than one-third minute. Excess of caustic is then squeezed out, and the goods are neutralised by passage through a fairly strong (30 grams of sulfuric acid per liter) but cold acid bath. By suitable weaving various pattern effects may be obtained.

The method of treating wool with strong alkalies for the purpose of increasing the affinity of the fiber for dyes is suggested as a means of obtaining two-colored effects in wool printing.[1] The following recipe was recommended for practical work: Print the goods with a mixture of 400 parts of caustic soda solution (75° Tw.), 400 parts of tragacanth solution (1 : 1000), 75 parts of British gum, and 150 parts of glycerol. After printing, wash without previous drying and then dye. It is also said to be advisable to pass the goods through a bath containing 50 lbs. of ammonia per 100 gallons. Knecht,[2] however, states that this method does not give satisfactory results, but on investigation finds that the following printing recipe is satisfactory: Print the goods with a mixture of 100 parts of caustic soda solution of 80° Tw. and 100 parts of British gum (1 : 1). This treatment gives excellent results with the acid dyes.

Chevreul showed that wool treated to the action of lime in a cold solution and without access of air takes up dyes more readily than untreated wool. Guignet and David[3] find this property is general for all ordinary dyes. The effect is obtained by treating the wool skeins of fabric with a milk of lime solution containing 0.5 lb. slacked lime for 100 lbs. of wool.

A product known as "Protectol" has recently been introduced in Germany as a substance for the treatment of wool so as to protect the fiber against the destructive action of alkalies. By the addition of this

[1] Cassella & Co., 1898.
[2] *Jour. Soc. Dyers & Col.*, 1898, p. 99.
[3] *Compt. rend.*, vol. 128, p. 686.

material to any bath containing caustic soda, it is said to be possible to treat wool in such a bath without injury to the fiber. It is being employed considerably in the dyeing of sulfur colors on mixtures of wool and cotton, the wool being thus protected from the corrosive action of the sodium sulfide in the dye-bath. Protectol is a by-product obtained from the waste sulfite liquors in cooking wood-pulp. It probably consists largely of the sodium salt of lignin sulfonate.

Schneider[1] states that when woolen yarn is boiled for fifteen minutes in a bath containing 13 cc. per liter of a 4 percent solution of caustic soda, and the liquor is then run off and the yarn treated with an equivalent amount of sulfuric acid, the yarn can then be mordanted with the use of bichromates and be finished in much less time than when the treatment with caustic soda is omitted; also the wool material treated with caustic soda is softer and has a greater affinity for dyestuffs than the untreated wool.

Burton and Barralet[2] have studied the action of sodium peroxide together with caustic soda on wool. Two solutions were prepared, the one of plain caustic soda of $4\frac{1}{2}°$ Tw., and the other of caustic soda and 0.7 percent of sodium peroxide; glycerol was added to the solutions. Two samples of woolen blanket cloth were placed in each solution, and it was observed that in a few minutes the piece in the plain caustic soda solution had turned to a yellowish brown color, while the piece in the peroxide bath kept its original color. After the pieces had been immersed for one hour they were taken out, washed with water and soured in dilute sulfuric acid. The piece from the plain caustic soda bath lost some of its brown color and developed a strong odor of hydrogen sulfide. The other piece improved somewhat in color and gave no odor. After drying it was found that the sample from the peroxide bath showed much less shrinkage than the other and when dyed with Victoria Blue gave a bright blue color, while the other gave only a dull color.

The exact nature of the action of caustic soda under the conditions given is rather difficult to satisfactorily explain. Through a microscopic examination of the treated fibers it appears that the individual scales on the surface of the wool are more or less fused together to a smooth surface, which would account for the great increase in luster. The additional tensile strength is probably accounted for by the same fact, the closer adhesions of the scales giving a greater rigidity to the fiber. The volatile alkalies, such as ammonia and ammonium carbonate, do not have any marked deleterious effect on wool, especially at low temperatures; hence these compounds form excellent scouring materials. The hydroxides of the alkaline earths, though less violent in their action

[1] *Jour. Soc. Dyers & Col.*, 1910, p. 24.
[2] *Dyer & Calico Printer*, 1899.

than the fixed caustic alkalies, nevertheless decompose wool. Milk of lime, even in the cold, abstracts most of the sulfur, and also causes the fiber to become hard and brittle if the action is prolonged; the wool also loses its felting quality to a considerable extent. Barium hydroxide, as previously noted, is used for the decomposition of wool in the preparation of lanuginic acid. Various processes for the treatment of wool with caustic alkalies in connection with glucose have been patented, as follows: Cassella, *Fr. Pat.* 316,243, dyeing of union goods with sulfur dyes; Badische, *Fr. Pat.* 28,696, boiling-off and mercerising cotton-silk fabrics; Badische, *Ger. Pats.* 110,633; 117,249; and 129,451 for the boiling-off of raw silk in fabrics containing silk and cotton or wool. See also Horace Koechlin, *Färb. Zeit.*, 1898, p. 35, for the use of caustic soda solutions in the printing of wool to obtain two-color effects.[1]

It is claimed by Karin that wool may be protected against the destructive effect of alkalies at high temperatures by a treatment with formaldehyde.

According to Bethmann[2] wool which has been treated with caustic soda loses its reducing properties; for instance, wool prepared in this manner may be printed a good Aniline Black with the usual aniline padding mixture without increasing the proportion of potassium chlorate[3] as is usually the case on ordinary wool.

Gelmo and Suida state that alcoholic caustic potash colors wool yellow while at the same time materially increasing the affinity of the fiber for substantive dyes in a neutral bath.

Schneider[4] reports the rather remarkable observation that by boiling wool for fifteen minutes with a bath containing 13 cc. of normal caustic soda solution per liter, and rinsing in a bath containing the equivalent quantity of sulfuric acid, it is then possible to mordant the wool directly with chrome without the usual addition of any reducing assistants (such as cream of tartar). The chroming is said to proceed more rapidly and the mordanted wool dyes better, while it has a softer feel and is not so sensitive to light as ordinary chrome-mordanted wool.

Where it is necessary to use alkalies in the treatment of wool, as for example, in neutralising after carbonising with acid, caustic alkalies must be avoided, and only ammonia or dilute solutions of soda ash used. Even the latter, however, has a destructive action on wool if used hot (above 140° F.) or if used in concentrated solutions. Ammonia, also, must not be employed too strong or too hot. The alkalies having the least effect on wool, perhaps, are ammonium carbonate and borax.

[1] Also see *Zeit. Farb. Ind.*, 1902, pp. 266 and 372.
[2] *Zeit. angew. Chem.*, 1906, p. 1817.
[3] *Ger. Pat.* 170,228.
[4] *Jour. Soc. Dyers & Col.*, 1910, p. 24

Sodium phosphate is also a mild alkali which may be used in connection with wool without fear of injury. Potassium carbonate is said to have a less injurious effect than soda ash, and on this account is still quite extensively used in wool scouring in spite of its higher cost.

Whenever woolen goods are treated with alkaline solutions of whatever character, great care should be had to give the material subsequently a most thorough washing in order to remove the last trace of alkali as otherwise after drying and storing alkali spots may form, resulting in a weakening of the fiber and a discoloration of the goods. Also if subsequently dyed the pieces may exhibit streaks or spots due to the action of alkaline residues in affecting the dyeing properties of the fiber.

6. Action of Reducing Agents.—Reducing agents in general have no action on the wool fiber itself, though they reduce the coloring matter in wool and consequently are useful as bleaching agents. Reducing agents include such substances as sulfurous acid, sodium bisulfite, sodium hydrosulfite, zinc dust with acetic acid, stannous chloride, titanous sulfate, etc. They act in a manner opposite to oxidising agents in that they eliminate oxygen from the substance on which they act. The action of a boiling solution of sodium bisulfite, however, is remarkable, though it is not exactly certain in this case whether it plays the part of a reducing agent or an acid salt. According to Elsässer [1] a sort of " mercerisation " of the fiber takes place when wool is boiled with a concentrated solution of sodium bisulfite. The fiber acquires a soft, gummy character and shrinks considerably. When this point is reached the material is then stretched back to its original length and fixed by washing in cold or hot water, or in solutions of such substances as neutralise bisulfite, such as hypochlorite, etc. The strength of the treated wool is said to be greater than the original, while the fiber acquires a high degree of luster. There is no record as yet, however, of this process becoming commercially successful.

7. Action of Oxidising Agents.—Toward many other chemical reagents wool is much more reactive than cotton, and either absorbs from solution or chemically combines with many substances. The fiber is quite readily oxidised when treated with strong oxidising agents such as potassium permanganate or bichromate, becoming greatly deteriorated in its qualities.

When treated with solutions of **hydrogen peroxide** the wool fiber becomes bleached, as the coloring matter, or pigment, is destroyed. Under ordinary conditions of use, solutions of hydrogen peroxide do not have any deleterious effect on the qualities of the wool fiber itself. On this account this reagent is largely employed for the bleaching of woolen materials, or materials containing mixed cotton and woolen yarns. Instead of employing a solution of hydrogen peroxide itself, **sodium peroxide** may be dissolved in acidulated water (with sulfuric acid), giving a slightly acid

[1] *Ger. Pat.* 233,210.

solution of hydrogen peroxide. The slight excess of acid is used for the purpose of completely neutralising all of the caustic soda that is formed when sodium peroxide reacts with water, as the presence of any free caustic soda in the bleaching bath would be injurious to the wool. When employed for active bleaching, the bath is usually made slightly alkaline by the addition of ammonia, silicate of soda, borax, or sodium phosphate.

Dilute solutions of **potassium permanganate** may also be employed for the bleaching of wool. The solution should not contain more than 2-3 percent of potassium permanganate on the weight of the wool, and the temperature of the bath should not be over 120° F., otherwise there is danger of damaging the fiber. When steeped in such a solution of potassium permanganate the wool acquires a dark brown color by reason of the precipitation of a hydrate of manganese in the fiber. Subsequent treatment with a solution of oxalic acid or of sodium bisulfite removes the manganese compound, leaving the fiber clear and white. This is a very effective method of bleaching wool, as a good white can be obtained in a short space of time; the fiber, however, always acquires a harsh feel and a scroop, owing to the oxidising action of the permanganate on the outer scales of the fiber. The method is also too expensive for general use.

Kertesz [1] has made some interesting tests on the action of atmospheric agencies on wool and fabrics made therefrom. He states that exposure to light destroys scoured wool most rapidly, dyed wool next, and wool treated with chromium salts least rapidly. The use of chromium salts for improving the resistance of wool is the subject of patent.[2] Acid salts, such as alum and iron salts, have a useful effect, but are inferior to chromium salts. Fats and lanolin proved to be harmful additions. Prolonged action of ozone weakens wool, but the fiber remains soft and elastic. Exposure to ultra-violent light gives accelerated changes similar to those caused by weather exposure. The biuret reaction is useful for determining the extent of injury caused by weathering. Wool exposed to atmospheric agencies becomes acid in reaction owing to the sulfur in the fiber being oxidised to sulfuric acid.

8. Action of Chlorine on Wool.—Toward chlorine, wool acts in a peculiar manner; it is completely decomposed by moist chlorine gas, but in weak solutions of hypochlorites it absorbs a considerable amount of chlorine and is strangely altered in its properties. It becomes harsh, has a high luster, and acquires a silklike feel or "scroop," at the same time losing its felting properties though its attraction for coloring matters in general is largely increased. The assertion by Witt (*Gespinstfasern*, p. 9) that chlorinated wool is soluble in ammonia with evolution of nitrogen is denied by Grandmougin.[3] The action of chlorine on wool was first

[1] *Färber Zeitung*, vol. 30, p. 137. [2] *Ger. Pat.* 286,340.
[3] *Zeit. Farb. Ind.*, 1906, p. 399.

noticed by Mercer, and in 1865 Lightfoot introduced the chlorination of wool into practice for the purpose of dyeing aniline black on wool. He states that wool is worked in a solution of bleaching powder for twenty to thirty minutes, and then passed through an acid bath. For the preparation of the bath Lightfoot used 2 ounces of bleaching powder per gallon of water, and this he states is sufficient for the treatment of 1 lb. of cloth. For investigations relating to the chlorination of wool see Knecht and Milnes, *Jour. Soc. Dyers & Col.*, 1892, p. 41; Grandmougin, *Zeit. Farb. Ind.*, 1906, p. 396; Vignon and Mollard, *Jahres-Berichte*, 1907, p. 386; and Pearson, *Jour. Soc. Dyers & Col.*, 1909, p. 81.

Bromine appears to have a similar action on wool. It is claimed to have the advantages over chlorine in that it does not turn the material yellow, and that in mixtures of dyed and undyed wool the former is not attacked. This latter statement is open to doubt.

By the chlorination of wool is meant the treatment of the fiber with a solution of hypochlorite in such a manner that the strength and other good qualities are not seriously affected, while at the same time the substance of the fiber appears to undergo rather remarkable transformation, leading to a considerable alteration in its chemical properties. **Chlorinated wool** finds quite a number of applications in practice. The process is used for instance, for the purpose of imparting a silklike gloss to the fiber. The process of chlorination is employed principally in the printing of woolen fabrics so as to prepare a print cloth which will more readily take the dyestuff. It is also used to a considerable extent for the preparation of yarns, so as to lessen their felting qualities and at the same time increase their dyeing properties.

If yarns of chlorinated wool and ordinary wool are woven together in pattern, and the fabric afterward fulled, since the chlorinated wool does not felt it will not shrink up like the remainder of the yarn, and in consequence the pattern will be brought out with very good effect; a great variety of novelties may be produced in this manner. Finally, the property of chlorinated wool to dye a heavier shade than ordinary wool, when dyed in the same bath, is also utilised; and fabrics with beautiful two-color effects may be easily obtained in this manner by weaving the chlorinated wool into designs with ordinary wool and afterward dyeing with suitable coloring matters. A slight chlorination is also given to woolen cloth to be used for printing so it will take the colors better; see also Farbw. Höchst, *Fr. Pat.* 267,004.

The chlorination of the woolen yarn is carried out in practice as follows: The material is well freed from all greasy matters by a preliminary scouring; this must be very thorough, otherwise good results will not be obtained, as the yarn is liable to finish up very unevenly. A steeping in hydrochloric acid next takes place; the solution should be cold and have a density of

$1\frac{1}{2}°$ Tw. The wool should be left in this bath for twenty minutes. It is next passed into a solution of bleaching powder standing at 3° Tw. and worked for ten minutes, after which it is again treated with the solution of hydrochloric acid and washed thoroughly.[1] It is said that sodium hypochlorite is better to use than chloride of lime, and sulfuric acid is preferable to hydrochloric, showing less tendency to turn the material yellow. The yellow color due to the chlorine may be removed by treatment with sulfurous acid.[2]

According to a recent German patent, the harshness of chlorinated wool may be considerably lessened by working the material first in a solution of a salt such as citrate of zinc or acetate of iron, or of sodium stannate or aluminate; this is followed by a second bath of very dilute alkali, after which the goods are exposed to the air.[3] The author, however, has not been able to obtain any satisfactory results on testing this process.

According to Pearson the following is the chlorination method in use for the manufacture of unshrinkable woolen underwear. The fabric is treated with a solution of sodium hypochlorite containing not more than 4.5 percent of available chlorine. After each addition of the hypochlorite solution the liquid is acidified with hydrochloric acid. After the chlorine treatment the wool is thoroughly rinsed, and then treated with a bath of sodium bisulfite for the purpose of removing excess of chlorine from the fiber and restoring its color. A final washing and scouring with a soap solution containing a little soda ash is given. Pearson claims that chlorinated wool may be distinguished from untreated wool by allowing a drop of water to fall upon it. With chlorinated wool the drop is rapidly absorbed, forming a circular spot; whereas with untreated wool the drop is slowly absorbed and the outline of the wetted portion is irregular. Also if fabrics of the treated and untreated wool be rubbed together a considerable electric charge will be formed. This property of chlorinated wool had formed the basis of a patented "electric" belt. Garments of chlorinated wool, however, do not wear well, and are rapidly deteriorated by laundering.

The chemical action of the chlorine on the wool is evidently that of oxidation rather than a combination of the fiber with the chlorine. The increased luster and the loss in felting properties is no doubt due to the partial destruction of the external scales on the surface, or rather the softening and fusing together of the free protruding edges of these scales. Microscopic examination seems to favor this opinion.

[1] See Cassella, *Fr. Pat.* 279,381, and *Ger. Pat.* 108,714. See also Platt, *Färber-Zeit.*, 1898, p. 3, for the chlorination of wool with the use of sulfuric acid and chloride of lime.

[2] See Farbw. Höchst, *Ger. Pat.* 95,719, for the chlorination of wool by the use of chlorine gas.

[3] See Florin and Lagage-Roubaix, *Ger. Pat.* 123,097 and 123,098.

It is said that the same effects produced in the chlorination of wool can be obtained by the use of potassium permanganate in a 10 percent solution acidified with sulfuric acid.[1] This, however, would be far more expensive, and it has not been demonstrated that the effects are equivalent.

According to Lodge,[2] when chlorinated wool is treated with potassium bichromate for mordanting previous to dyeing, the fiber is much deeper in color than when ordinary wool is employed. On estimating the amount of chrome taken up by the fiber in each case it was found that when using 3 percent of potassium bichromate the chlorinated wool took up 2.29 percent and the ordinary wool only 1.16 percent.

Knecht, in a series of experiments on the mordanting of wool with chromium, has shown that chlorinated wool may be mordanted with chrome alum without any decomposition being noticeable in the bath. A 10-gram sample of ordinary wool was treated with 600 cc. of water and 2 grams of sulfuric acid, then well squeezed and mordanted with 10 percent of chrome alum, and in this case no decomposition in the mordant bath was noticeable. If, after the treatment with acid, the wool is steeped for a quarter of an hour in a cold dilute solution of bleaching powder, then washed and mordanted with chrome alum, no decomposition of the chrome alum occurs in the bath, but there is observed an interesting formation of chromic acid. Apart from the effect of the oxidation of the wool, possibly the good results obtained on chlorinated wool in the dyeing, at least with certain coloring matters, may depend to some extent, according to Knecht, upon the acid absorbed by the wool. In the case of the above test the two samples, when dyed with Alizarine, have a garnet red color on the non-chlorinated sample, pointing evidently to the effect of the acid absorbed by the wool, whereas the second or chlorinated sample gave a bluish bordeaux red color, due, no doubt, to the presence of lime in the wool.

The general method of carrying out the chlorinating of woolen cloth is as follows: A solution of bleaching powder is prepared of such strength that it contains from 4 to 5 percent of available chlorine, which would correspond to a solution standing at about 17° Tw. A solution of sodium carbonate is now added in a slight excess with constant stirring. This will cause a precipitation of the lime as carbonate of lime, and on allowing this precipitate or sediment to settle, the clear liquor containing sodium hypochlorite in solution may be decanted. The solution will contain about 4 percent of available chlorine, and should have a specific gravity of about 1.1. It is well to have a slight excess of alkali in the solution, so that the subsequent liberation of the chlorine may take place gradually. Solutions of greater strength are liable to form chlorate of soda, which has a bad effect on the wool, in that it tends to color it yellow.

[1] Kammerer, *Brit. Pat.* 5612 of 1907. [2] *Jour. Soc. Dyers & Col.*, 1892, p. 60.

For the chlorination proper from ½ to 1 pint of this sodium hypochlorite solution is required per pound of wool. Hydrochloric acid is also added to the solution gradually to the extent of about the volume of the hypochlorite solution. The goods are run through this liquor and then well rinsed. After the treatment it will be found that the wool has acquired a somewhat yellowish color. This may be removed by running the goods through a bath containing 100 gals. of water, 1 gal. sodium bisulfite liquor, and 1 pint of previously diluted sulfuric acid. In place of the bisulfite treatment, a bath of stannous chloride and hydrochloric acid may be used. After a thorough rinsing, the goods are finally scoured with soap to which is added a little sodium carbonate. This is added for the purpose of softening the handle or feel of the fiber.

In describing the chlorination of wool most experimenters on this subject have insisted that a prolonged action of chlorine on wool is to be avoided, as it imparts to the fiber a yellowish color and a harsh, unpleasant feel. It is also generally stated that a chlorine bath which has once been used for the treatment of woolen goods can be again strengthened for further use by the addition of an amount of hypochlorite considerably less than the original quantity. Bullard,[1] however, takes exception to these statements. He points out that while the chlorinating of cotton is a gradual and progressive action, the reaction with wool, however, is a very rapid one, and the entire amount of the chlorine is absorbed by the wool in a few minutes; consequently the strengthening of old liquors for further use is quite unnecessary.

Bullard made experiments showing these conclusions by using a piece of woolen fabric weighing 20 grams which had previously been subjected to the operations of soaping, stoving, washing, etc. A solution was prepared containing 5 grams of sulfuric acid and 12 cc. of hypochlorite of soda (corresponding to 0.6 gram of dry bleaching powder of good quality) in 1 liter of water. One volume of such a solution immediately decolorises one volume of a solution of indigo in sulfuric acid so diluted that its color is just visible. The wool is steeped in the chlorine bath for one minute, and, after removing it, the bath no longer decolorises indigo solution, thus showing that all of the chlorine has been removed by the wool. Sometimes, indeed, half a minute is sufficient for the removal of all the chlorine. A further addition of 12 cc. of hypochlorite solution is made to the bath, and the wool is entered again for a minute. On testing the bath it will be found that all the chlorine has again been abstracted. This may be repeated several times, provided care is always taken that an excess of acid be present. After three or four of such operations the wool acquires a yellowish tint and a harsh feel. Even when the hypochlorite bath is four times as strong as that given above (that is to say, equivalent to

[1] *Monit. Scient.*, 1894.

12 percent of bleaching powder on the weight of the wool) every trace of chlorine will have been removed by the wool in a treatment of two minutes.

From this it is to be seen that the essential point for consideration in the chlorination of wool is very evidently the relative proportion of chlorine and wool rather than the time of action. According to Bullard, the best proportion is from 2 to 5 percent of bleaching powder or its equivalent in terms of sodium hypochlorite on the weight of the wool being treated. If calcium hypochlorite be used, the acid employed must be hydrochloric, whereas with the use of sodium hypochlorite either hydrochloric or sulfuric acid may be employed; but in any case, an excess of acid should always be present in the solution. As hydrochloric acid tends to render the wool yellow when used in this connection, the employment of sodium hypochlorite with sulfuric acid is to be preferred. The acid bath may precede or follow the chlorine bath. Preferably the former method of treatment is to be used. The amount of acid is of secondary importance, as it is only necessary that an excess should be used. An important point in the chlorination of wool is that of bringing as soon as possible the entire bulk of the wool under treatment into contact with the liberated chlorine. When treated on the jigger or over a winch there is great danger of the pieces being " ended " owing to the rapid absorption of the chlorine. In using chloride of lime for the chlorination it is necessary to avoid the use of sulfuric acid, as the insoluble calcium sulfate that is formed adheres tenaciously to the wool. With hypochlorite of soda either sulfuric or hydrochloric acid may be added.

A mechanical difficulty which has to be overcome is that of obtaining as even as possible an absorption of chlorine by the fiber. If treated in the chain-form, those portions of the material reaching the liquor first absorb too much chlorine, while the latter portions receive little or none. It is better, therefore, in the treatment of cloth to carry out the operation in open width, making use of a frame similar to that employed for the dyeing of cloth in the open width in indigo vats. However, the parts of the frame must be constructed of some material capable of resisting the prolonged action of hypochlorite solutions. The rapid removal of the chlorine from the hypochlorite bath might have been attributed to the action of the sulfuric acid present in the stoved wool, but this conclusion was shown to be wrong by the results of an experiment carried out with a piece of woolen cloth which had been stoved but not subsequently washed. This piece was steeped in the acid bath, and then in the sodium hypochlorite liquor, and finally in a second bath containing sulfuric acid. In this last bath a considerable evolution of sulfur dioxide took place, but on washing, the wool was found to be satisfactorily chlorinated. Evidently the sulfuric acid and hypochlorite reacted to produce chlorine, and a certain amount of the liberated soda combined with the

sulfurous acid to form sodium sulfide, this being decomposed in a second bath with liberation of sulfur dioxide. The satisfactory result of the chlorination indicates that in the presence of wool and sulfurous acid chlorine is more readily absorbed by the fiber than neutralised and rendered inactive by the sulfurous acid.

Trotman [1] points out that some of the properties that are usually attributed to chlorinated wool relate only to wool which has been improperly treated with the result of more or less breakdown in the fiber. The increased affinity of dyes, for example, is a property to be found only in wool that has been chlorinated overmuch; whereas properly treated fiber will not show such a property. The wetting power of properly chlorinated wool is also not much greater than that of ordinary wool. The change in properties has been shown to be due to damaged fibers. Trotman thinks that the customary methods of chlorination are too indefinite in the control of the conditions, particularly with regard to strength and amount of chlorine reacting with the fiber. Trotman comes to the conclusion that wool is more easily damaged by chlorine than by hypochlorous acid; hence bleaching-powder solution should be used under conditions that minimise the quantity of chlorine present. When using bleaching-powder solution and a mineral acid it is rarely safe to exceed the strength of 0.6 gm. of available chlorine per liter. The practice of soaking in the acid is dangerous, unless the quantity of acid is carefully controlled, since the excess of acid carried over into the bleach liquor causes evolution of chlorine. Excess of hypochlorous acid or of chlorine causes destruction of both epithelial scales and cortical scales and gives bad wearing qualities to the fiber. Instead of using hydrochloric acid, as is generally done, Trotman recommends the use of boric acid as giving a suitable chlorination without injury to the fiber.

The lustering of wool by chlorination finds a rather extensive application in the lustering of oriental rugs. These rugs after importation into this country are generally "washed" by treating with a solution of chloride of lime. This solution is usually just swabbed on the surface of the spread-out rugs and serves the purpose of both lustering the fiber and also of dulling the colors somewhat, so as to give the rugs an "antique" appearance. The natives in India and Persia dye the rugs in rather bright colors and when first imported the rugs have an appearance of newness about them which is not attractive to the trade. As the treatment with chloride of lime is rather crudely done and frequently the excess of bleach is not removed from the rug by proper washing, the method of treatment often leads to very disastrous results as far as the durability of the rug is concerned. A treatment with a strong solution of caustic soda is also frequently given the rugs for the purpose of lustering

[1] *Jour. Soc. Chem. Ind.*, 1922, p. 219.

the fiber. It has already been pointed out that such a treatment has this effect on the wool fiber. But here again the process should be very carefully done in order to avoid injury to the fiber. Another method of lustering rugs is recommended, as follows:

A preparation is made up of

16 gallons of water
66 lbs. best white soap
4 quarts olive oil
4 quarts cocoanut oil
12 quarts cottonseed oil
4 quarts borax

The preparation is placed in a vessel and boiled, and then mixed with cold water in the proportion of 1 quart of the mixture to 7 quarts of water. This fluid may then be sprayed on to the fabric to be treated, during the last few rounds of straightening in the gig or raising machine.

W. H. Schweitzer [1] describes a process for the chlorination of wool in connection with other processes for the production of waterproof fabrics as follows: Fifty kilos. of a fine wool cloth are treated at ordinary temperature with a filtered solution of 40 kilos. of chloride of lime in 1500 liters of water to which an equivalent quantity of hydrochloric acid has been previously added, until the developed hypochlorous acid disappears, which is generally the case after half an hour. The cloth is then abundantly rinsed with cold water. Afterward it is bleached by dipping it into a solution of sodium hydrosulfite or of sulfurous acid and rinsed. Then the bleached fiber is boiled in a solution of 3 kilos. of wax soap in 1500 liters of water and rinsed in cold water. The wax soap employed is prepared by saponifying 3 parts of beeswax with 3 parts of solid soda lye. The cloth is then treated for a relatively short time, varying from a few minutes to one-quarter of an hour, according to the thickness of the fiber or other reasons, with a solution of 15 kilos. of solid soda lye in 1500 liters of water, wrung out and again copiously rinsed with water. Finally the cloth is boiled in a solution of Castile soap, to which at the end some acetic acid has been added, dried and calendered.

9. Action of Formaldehyde on Wool.—When wool is treated with a 4 percent solution of formaldehyde it is made much more resistant to alkalies and also shows a decreased affinity toward dyestuffs. Kann has described this use of formaldehyde as a means of dyeing wool with vat dyes in which a strongly alkaline bath is employed. The formaldehyde may be added directly to the alkaline bath. It is also claimed that sulfur dyes may be applied to wool in the same manner. Wool treated with formaldehyde is said to be much more resistant to the action of steaming than untreated wool. There have been many attempts to devise a method

[1] *U. S. Patent* 1,389,274.

of treatment whereby the wool fibers could be protected from the destructive action of the alkali which is required in dye baths employed for these colors. Kann has taken out a number of patents during the last few years describing the use of formaldehyde for this purpose. It was first recommended to employ a 4 percent solution of formaldehyde for the treatment of the wool, but it is now pointed out that the use of such a solution, although protecting the wool to a considerable degree against action of the alkali, decreases greatly its affinity for dyestuffs. In later patents formaldehyde was added to the alkaline dye bath, and it was eventually discovered that only small quantities of formaldehyde are necessary to produce the desired effect. When used in these proportions the formaldehyde does not decrease the affinity of the wool fiber for dyestuffs. It is only necessary to use an amount of commercial formaldehyde equivalent to $\frac{1}{4}$ to $\frac{1}{10}$ of 1 percent of the weight of the bath used to produce the desired effect. For example, about 3 ozs. of commercial formaldehyde per 10 gallons of water is all that is necessary. In cases where the wool is to be treated with formaldehyde before its immersion in the dye bath, it is necessary to make the formaldehyde solution slightly acid by the addition of a small quantity of sodium carbonate. If formaldehyde is added directly to the dye bath, it should be allowed to act slowly by maintaining the bath at a comparatively low temperature for several minutes. It has previously been considered that the action of formaldehyde was a catalytic one, but when the treated wool is moistened with hydrochloric acid and heated, formaldehyde is liberated in a sufficient quantity to render it evident that a chemical composition has occurred between the substance of the wool fiber and the formaldehyde itself. By use of formaldehyde treatment of wool it has been found possible to dye this fiber with various sulfur colors in the dye bath in which a considerable quantity of the strong alkali sodium sulfide is necessarily present to maintain the solution of the dyestuff. This same treatment can also be employed on woolen material which is subsequently subjected to the action of steaming, and thereby the deleterious effect on the fiber of the steaming operation is said to be reduced by 80 percent. Furthermore, raw wool which has been treated with formaldehyde may be scoured with a solution containing $\frac{1}{10}$ percent of caustic potash and a little soap without any special detrimental action on the fiber. This process of treatment is also available for use with goods made up of cotton and woolen mixtures. It is possible that the action of formaldehyde on wool is to be explained by a condensation of the formaldehyde with the amino group in the substance of the wool fiber. It is furthermore stated that wool which has been treated by the formaldehyde method is not seriously affected by immersion for twenty minutes in a 20 percent solution of sodium carbonate somewhat below the boiling point. At a temperature of 160° F. the

wool is not affected by even $\frac{1}{2}$ percent solutions of caustic alkali, and it is also unaffected by treatment with boiling water.

For the preservation of wool against the action of alkaline solution also see reference to Protectol or the sodium salt of lignin sulfonate prepared from sulfite pulp waste liquors.

10. Action of Metallic Salts; Mordants.—With *neutral* metallic salts wool does not seem very reactive, as it does not absorb them appreciably from their solutions. Neutral salts of the alkali or alkaline-earth metals, such as common salt, glaubersalt, potassium chloride, magnesium sulfate, etc., have no action on wool. Even in boiling solutions the fiber hardly absorbs the slightest trace. Toward certain salts, however, wool acts as a reducing agent; this being the case with potassium nitrate which is reduced to potassium nitrite.[1] With salts of the heavy metals, however, and more particularly those of aluminium, iron, chromium, copper and tin, wool is very reactive; the salts include the sulfates, chlorides, nitrates, acetates, formates, oxalates, tartrates, etc. When boiled with these solutions the substance of the wool combines with the basic salt or with the metallic hydroxide though in just what manner is not yet accurately determined.[2]

From experiments of Bland and Fort [3] it would seem that solutions of glaubersalt (as an example of a neutral salt solution) have a slight dissolving action on the substance of the wool fiber. By treating 5 grams of wool with a solution of 1 gram of glaubersalt in 150 cc. of water at the boil for three hours, there was a loss of wool substance amounting to 0.5 percent on the weight of the fiber. A similar test with pure silk gave a loss of 0.6 percent.

With salts, which are *acid* in reaction and are capable of being easily dissociated, such as alum, ferrous sulfate, potassium bichromate, etc., the wool fiber possesses considerable attraction, especially when boiled in their solutions. On this reaction, in fact, are based the important methods of mordanting wool with various metallic salts as a previous preparation for the dyeing of many coloring matters.

According to Gelmo and Suida [4] when wool is boiled for one hour in a solution of alum acidified with sulfuric acid, a considerable hydrolysis is caused, there being considerable loss in weight, and the formation of soluble amino acids. Some of the decomposition products resemble peptones in their action. Wool treated with a 0.1 percent solution of alcoholic zinc chloride and washed shows a decidedly decreased affinity for basic dyes and a greater affinity for acid dyes.

[1] See Schwalbe, *Färbetheorien*, p. 58.

[2] For the action of salts of organic bases on wool, see Schwalbe *Färbetheorien*, p. 158.

[3] *Jour. Soc. Dyers & Col.*, 1915, p. 178.

[4] *Monatsch. f. Chemie*, vol. 26, p. 855.

Schellens[1] has furnished some interesting experiments showing the relative power of fixation of metallic salts possessed by various textile fibers. With solutions of ferric chloride, for instance, the following results were obtained:

	Solution No. 1 Containing 1 Percent of Iron.	Solution No. 2 Containing 0.1 Percent of Iron.
Cotton-wool	0.112	0.112
Filter-paper	0.23	0.123
Vegetable silk	1.01	0.56
Jute	0.56	0.44
Raw silk	0.67	0.67
Wool	0.84	0.36

The figures refer to the weight of iron fixed by 1 gram of the fiber from 50 cc. of the respective solutions.

The metallic salt chiefly employed for the mordanting of wool is potassium bichromate though of late years sodium bichromate has largely replaced the potassium salt. The sodium salt is less costly, but has the disadvantage of absorbing moisture from the air, and therefore unless carefully stored its strength is liable to change. When properly handled, however, sodium bichromate gives as good results as those obtained with the potassium compound. The following table gives the solubility of the two salts in 100 parts of water;

	32° F.	176° F.	212° F.
Potassium bichromate	5	73	102
Sodium bichromate	107	143	163

If wool is simply boiled in a dilute solution of potassium bichromate, the fiber will take up from solution a considerable portion of the chromium compound, presumably in the form of a chromate of chromium; that is to say, a combination of chromic acid with chromic oxide. The substance of the wool fiber itself apparently has a reducing action on the potassium bichromate. It has been found that this action is promoted and accelerated by the presence of acids and certain organic compounds (such as tartar). Therefore it is customary to add such compounds to the mordanting bath. Sulfuric acid, tartar, lactic and formic acids are chiefly used for this purpose. It has already been pointed out that wool

[1] *Arch. Pharm.*, 1905, p. 617.

is capable of combining with acids (probably due to its basic nature); a similar reaction seems to take place when wool is boiled with tartar (potassium acid tartrate), the fiber combining with the tartaric acid and leaving normal tartrate in the bath. The same is also true with ammonium sulfate, the wool combining with the sulfuric acid and setting free ammonia.

The following table gives the equivalent amounts of various assistants to use with 3 percent of chrome [1] in mordanting:

	Percent.
Tartar	2.5
Lactic acid	3.0
Oxalic acid	2.0
Formic acid	1.5
Sulfuric acid	1.5

Tartar is said to give shades of a better "bloom" than any of the other assistants. Lactic acid does not have as good leading properties, but gives colors somewhat faster than those given with tartar. Oxalic, formic, and sulfuric acids exhaust the mordanting bath more completely and give the mordanted material the appearance of having more chrome on it, but they do not produce as good shades, and a slight excess of any of these three acids is liable to furnish poor colors.

When wool is mordanted with potassium bichromate and sulfuric acid, compounds of chromic acid and chromium oxide of a more or less yellowish color are fixed in the fiber. By increasing the proportion of sulfuric acid the mordant has a greener shade and is richer in chromic oxide. According to Ulrich [2] the reduction of the chromic acid is brought about by the products formed by the gradual hydrolysis of the fiber substance by the acid. When lactic and formic acids are employed in place of sulfuric acid, they simply accelerate the reduction. Experiments on the action of formic acid on chromic acid have shown that a fairly high reaction velocity is reached only with very high concentrations of the formic acid, for even with 500 molecules of formic acid per molecule of chromic acid, the reduction is not complete after boiling for one hour. Experiments in the presence of wool have shown that the formic acid has little influence on the reduction process, the conversion of the chromic acid into chromic oxide being caused, even in its presence, by the products formed by the hydrolysis of the fiber. The part taken by the formic acid in the mordanting of wool, therefore, is simply to accelerate the absorption of the chromium compounds by the fiber.

[1] The term "chrome" in dyehouse parlance is a general term for either potassium or sodium bichromate.

[2] *Zeit. physiol. Chem.*, 1908, p. 25.

11. Comparison of Various Mordants.—Grandmougin[1] has determined the power of mordanting wool possessed by salts of the following elements:

Copper	Boron	Lead	Tellurium
Silver	Aluminium	Thorium	Tungsten
Gold	Ytterbium	Vanadium	Uranium
Beryllium	Lanthanum	Arsenic	Chlorine
Magnesium	Thalium	Antimony	Manganese
Calcium	Silicon	Didymium	Bromine
Zinc	Titanium	Bismuth	Iodine
Strontium	Zirconium	Sulfur	Iron
Cadmium	Tin	Chromium	Cobalt
Barium	Cerium	Selenium	Nickel
Mercury	Erbium	Molybdenum	Platinum

The mordants employed were for the most part either the sulfate, nitrate, chloride or acetate of the metal, together with some assistant such as tartar, oxalic acid, or acetic acid. The mordanted wool proved to be white, gray, or pale yellow in color except with the copper and also in the following cases: Selenium dioxide with sodium bisulfite gave a brownish red color. Ammonium molybdate with hydrochloric acid and sodium bisulfite gave a pale blue color. Tellurium dioxide and sodium bisulfite gave a brownish black color. The mordanted patterns were dyed with various coloring matters as shown in the following table, and each pattern was divided into four portions, of which the first was merely washed with water, the second soaped at 60° C., the third exposed to the action of light, and the fourth tested for fastness to fulling. The results were classified according to the depth of color and the fastness, Class 5 comprising the deepest and fastest colors, Classes 4 and 3 being inferior in depth and fastness, Class 2 including the indifferent colors which were no deeper in color than those obtained on unmordanted wool and were easily removed by soaping, while in Classes 1 and 0 the results were negative, as these mordants serve as resists to the dyestuffs. Grandmougin does not consider it possible to establish any connection between the mordanting power of an element and its position in the periodic system. The comparative value of the elements as mordants may be expressed as follows: Useful mordants—Chromium, Uranium,—Titanium, Mercury, Thorium, Bismuth, Iron,—Aluminium, Copper, Tin,—Tungsten, Vanadium, Zirconium, Lead,—Lanthanum, Cerium, Ytterbium, Antimony,—Cadmium, Didymium, Cobalt, Nickel, Arsenic. Indifferent mordants—Beryllium, Magnesium, Calcium, Zinc, Strontium, Barium, Boron, Thallium, Manganese. Negative mordants (useful as resists)—Molybdenum, Platinum, Silver, Silicon, Erbium, Chlorine, Bromine, Iodine, Gold, Sulfur, Selenium, Tellurium.

[1] *Bull. Soc. Ind. Mulh.*, 1898.

Coloring Matters.	Useful Mordants.			Negative Results.	
	Class 5.	Class 4.	Class 3.	Class 1.	Class 0
Alizarine Red.....	Al, Ti, Th, Di, Cr, Ur	Cu, Hg, Zr, Zn, V, Bi, W, Fe	Y, La, Ce	Au, Si, Er, S, Mo	Se, Te
Alizarine Orange.....	Th, Bi, Cr, Ur, Fe	Ti, Zr, Ce, Pb	Cu, Al, Y, La, Sn, V, Sb, Di, W, Co, Ni	.....	Se, Te
Alizarine Blue S.....	Sn, Cr, W, Ur	Hg, Al, Ti, Pb, Th, V, Bi, Fe	Cd, La, As, Sb, Co, Ni	Be, B, Si, Er, Mo, Mn, Pt	Ag, Au, S, Se, Te, Cl, Br, I
Logwood.....	Cu, Hg, Cr, Ur	Al, Ti, Th, Bi, Mo, W, Fe	Be, Cd, B, Y, La, Zr, Sn, Ce, Pb, V, Sb, Mn	.....	Se, Te
Alizarine Yellow GG.....	Hg, Cr	Ti, Fe, Ur	Cu, Al	.....	Se, Te, Mo
Chromotrope 2B.....	Cr, Ur	Cu, Ti, Sn, Bi	Hg, Al, Th, V	.....	Se, Te

The action of tungstic acid and sodium metatungstate on wool has been investigated by Schoen.[1] It was found that wool which has been boiled with a solution of sodium tungstate has very little affinity for the acid dyes, whereas it will dye heavier colors with the basic dyes. The treatment with the sodium tungstate, therefore, has probably neutralised the basic functions and strengthened the acid functions of the wool. Tungstic acid[2] may be used to permanently protect woolens, furs, and hair from moths. The material is immersed in a 3 percent solution of colloidal tungstic acid to which sodium sulfate and sulfuric acid are added. The treatment may be applied before, during, or after dyeing.

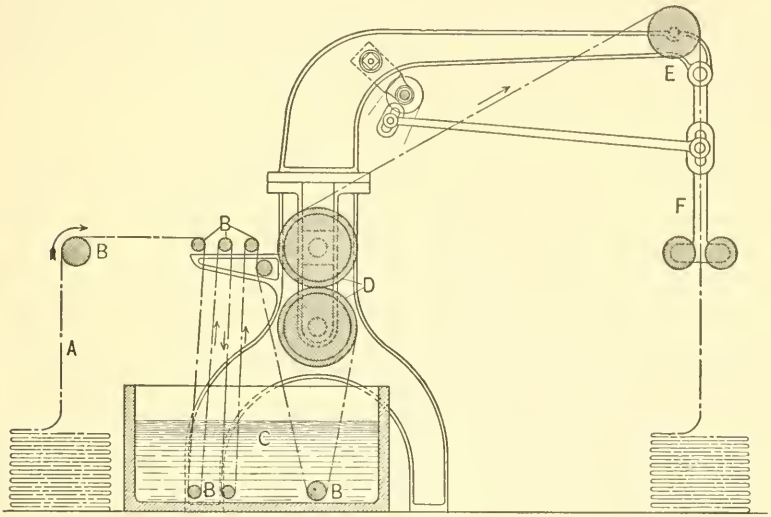


FIG. 76.—Machine for Weighting Wool Piece Goods.

12. Weighting Woolen Fabrics.—Certain metallic salts are used with wool for the purpose of giving increased weight to the fabric. Magnesium chloride is a most useful loading agent on account of its possessing great hygroscopic properties. The action which takes place when a wool cloth is passed through a solution containing magnesium chloride is that the cloth will absorb the chloride, which is permanently retained in the fabric in liquid form. Zinc chloride possesses similar properties to those of magnesium chloride. To a limited degree magnesium sulfate is employed as a loading agent. When this agent is absorbed—especially to a large degree—a white powder is deposited on the fiber of the fabric, which is more or less discernible. Glaubersalt, which is employed as a leveling agent during acid dyeing, may also be stated to be a loading agent. The

[1] *Bull. Soc. Ind. Mulh.*, 1892.

[2] According to Bayer, *Brit. Pat.* 173,536.

action of this salt is to deposit a precipitate on the fibers that constitute the fabric, which action results in increased weight. The amount of loading agent employed in the solution is controlled by the increased weight required.

The process of weighting is usually carried out after the scouring, dyeing, raising, cutting, and brushing processes. During the process of loading slight shrinkage has been developed; also, the cloth is in a wet condition, and in consequence drying and tentering must be subsequent operations. Figure 76 illustrates the type of machine employed for imparting weight to a fabric.

To illustrate the influence of the different loading agents, and also the effect of different quantities of these agents, the following tests have been carried out by E. Midgley (*Textile Manufacturer*). The cloth employed in every case was of a whipcord character.

INFLUENCE OF LOADING

Cloth Number.	Remarks.	Weight per Yard.	Amount of Moisture Contained.	Warp.		Filling.		Mean.	
				Strength.	Elasticity.	Strength.	Elasticity.	Strength.	Elasticity.
		Oz.	Percent.	Kilos.	Cm.	Kilos.	Cm.	Kilos.	Cm.
—	Unadulterated	15⅝	14	53.5	4.25	46.5	4.62	50.0	4.4
1	Magnesium chloride	18⅞	22	45.9	7.1	35.1	7.17	40.5	7.1
2	" "	22½	45	42.0	7.75	37.5	8.4	39.7	8.0
3	Magnesium sulfate	17⅞	17	52.6	5.15	48.0	6.1	50.0	5.6
3A	As 3, but washed in cold water	17⅞	15	49.0	6.05	46.75	6.2	47.8	6.1
4	Magnesium sulfate	20⅞	24	50.87	4.45	47.2	6.27	49.0	5.3
4A	As 4, but washed in cold water	17⅞	16	48.75	5.5	44.25	5.8	46.5	5.6

Wool is sometimes weighted surreptitiously with magnesium chloride. Cases have been reported where woolen yarns were habitually weighted 7.5 percent by incorporating with the yarn magnesium chloride to the extent of about 1.5 percent. This would cause an additional absorption of moisture so as to bring the weight up to 7.5 percent beyond what it normally was.

13. Action of Thiocyanates on Wool.—According to Siefert,[1] when wool is treated with a solution of calcium thiocyanate and then steamed a considerable contraction takes place without injury to the fiber; consequently it is possible to produce a crêpon effect in this manner on woolen cloth. The treated wool also has an increased affinity for acid dyes, but its affinity for basic dyes is reduced.

[1] *Bull. Soc. Ind. Mulh.*, 1899, p. 86.

Crêpon effects on woolen cloth made by the printing on of chemicals which cause a shrinkage of the fiber may be produced by several methods. (1) Schaeffer's process consists in printing on a suitable resist, then treating the entire fabric with a strong solution of sodium bisulfite and steaming. This causes a shrinkage of the entire piece except at the portions on which the resist is printed. (2) Siefert's process consists in the use of calcium or barium sulfocyanide and steaming. It has been shown, however, that though when once produced these crêpe effects are very permanent both to washing and stretching, yet the cloth when printed with sulfocyanide is very tender while under the influence of steam, and cannot stand any degree of tension, therefore great care must be taken in the handling of the goods. Schoen and Grandmougin in reporting on Siefert's method found that ammonium sulfocyanide causes no contraction of the fiber, while the sulfocyanides of calcium and barium do produce the effect.

14. Action of Zinc Sulfate.—According to Kopp [1] when wool cloth is treated with a solution of zinc sulfate of high density a crêping effect is produced. The process was carried out commercially in the following manner: The gray wool fabric is turned piece by piece in a wooden vat containing a solution of zinc sulfate at a strength of 500 grams per liter and heated to the boil by means of a lead coil. After treatment in this bath the goods are washed in boiling water until no longer acid to litmus; they are then bleached and chlorinated in the usual manner for printing. The crêpe obtained in this manner is said to withstand the various operations very well and the fabric shows very little tendency to turn yellow on steaming.

15. Treatment with Radium.—With the extension of radium to all manner of therapeutic uses it is natural to expect that the salts of radium would be employed in connection with fabric materials. A recent patent relates to the application of a salt of radium to fibers, and consists in taking material composed of vegetable or animal fibers and first cleansing and drying them. The fibers thus prepared are then placed in a suitable mordant—for example, either in a 10 percent solution of tannic acid or in a concentrated solution of alum, and then dried again by means of a stove or in the air, according to their nature. They are then placed in a solution of a salt of radium, the percentage being determined according to the strength it is desired to obtain. If, for example, catgut is to be treated, the solution may contain 20 mgm. of bromide of radium per cubic centimeter. For silk, wool, or cotton the percentage may be much higher. In general the fibers should not remain more than half an hour in the bath. The radium is fixed on the fibers, which then only require to be dried. This method of fixing the radium may be applied to the

[1] *Bull. Soc. Ind. Mulh.*, 1894.

treatment of cloths, silks, wool, cotton, and in a general manner to most threads and fabrics. It imparts to these latter the properties of radiferous substances, and consequently renders them radioactive without its being necessary, in order to fix the radium, to employ any varnish, gum, or other foreign adhesive substance.

16. Action of Dyestuffs on Wool.—With regard to coloring matters wool is the most reactive of all the textile fibers, combining directly with acid, basic, and most substantive dyestuffs, and yielding, as a rule, shades which are much faster than those obtained on other fibers.

There have been various opinions put forward as to the influence in dyeing of the active chemical groups in wool. If the phenomena of dyeing were principally of a chemical nature we would expect this influence to be a considerable one. In the case of acid and basic dyes, we have to deal with bodies possessing definite chemical characteristics—that is to say, acid dyes are acid in nature, while basic dyes have basic properties. From the facts previously put forward, that wool consists principally of an amino acid, and is therefore capable of exhibiting both acid and basic properties, it would be natural to expect that in dyeing with acid coloring matters there would be (to some degree at least) the formation of a compound between the acid of the dyestuff and the base of the wool. Likewise, in dyeing with basic coloring matters the basic portion of the dyestuff would combine with the acid portion of the wool. That such a combination in reality does take place can hardly be doubted, for many experimental facts have been adduced leading to such a conclusion.

In the dyeing of wool with acid colors it is generally necessary to add sulfuric, or other strong acid, to the dye-bath. It has usually been the accepted theory that these dyes are sodium salts of sulfonic acids, and that the addition of the sulfuric acid causes the liberation of the free color-acid, and the latter then combines with the basic group of the wool fiber. But it has previously been pointed out that wool combines readily with sulfuric acid, and that wool so treated can dye with the acid colors without further addition of acid. This would seem to indicate that the basic group of wool combines with sulfuric acid, and consequently the presence of the latter in neutralising the basicity of the wool should decrease its affinity for acid dyes, according to the above view of the dyeing process; but the opposite is the case. Furthermore, a large excess of sulfuric acid above the amount required to liberate the free color-acid of the dyestuff, should prove detrimental to the dyeing. Gelmo and Suida,[1] who have investigated the subject, show that by using purified wool and dyeing with free color-acids the intensity of the resulting color is independent of the presence of free mineral acid in the dye-bath; hence they conclude

[1] *Monatsch. f. Chemie*, vol. 26, p. 855.

that the rôle played by the excess of acid is to neutralise the lime combined with the acid groups of the wool.

Aside from the fact that wool combines directly with acid and basic coloring matters, it has also been shown that when the active chemical groups in the fiber are neutralised by proper chemical treatment, the reactivity of wool toward acid and basic dyes respectively is much decreased. The acid nature of wool may be almost completely neutralised by acetylation with acetyl chloride, and the resulting fiber shows but very slight reactivity toward basic dyes, and a correspondingly increased reactivity toward acid dyes.

The action of dyestuffs on the fibers has also been explained by electrical effects. Haldane, Gee, and Harrison [1] have shown that the average value of the potential difference between the various fibers and water is as follows:

Cotton	0.06 volt
Silk	0.22 "
Wool	0.91 "

This seems to support the views of Pelet-Jolivet and Wild, and Knecht and Battey, that dyestuffs are electrolytes, and ionisation is increased by dilution and rise of temperature. Wool and silk becoming negatively charged when in contact with water, it is natural that basic dyestuffs (which carry a positive charge) should be capable of dyeing them from neutral solutions; but when by the addition of acid, the electrical condition of the fiber is changed, the affinity for these dyestuffs is diminished, while the power of fixing the predominant negative ions of the acid dyes is increased.

Suida has found that when wool is heated with acetyl chloride at the temperature of the water-bath a copious evolution of hydrochloric acid takes place, indicating the formation of an acetyl compound. Wool, which has been thus treated and freed from all excess of the reagent by alternate rinsing with alcohol and water, is found to have lost to a great extent its affinity for the basic coloring matters. Wool treated with acetic anhydride shows the same effect. Microscopical examination in both cases does not exhibit any structural modifications in the fiber. On heating wool which has been treated in this manner with a weak solution of ammonium carbonate (a reagent which is capable of saponifying acetyl compounds), the wool again regains its normal character with respect to its behavior toward basic dyestuffs. A change of the same character in wool is produced by heating the fiber on the water-bath with alcohol in the presence of a small amount of strong sulfuric acid. This treatment

[1] *Proc. Faraday Soc.*, 1910.

also appears to form an ester which is saponified by treatment afterward with an alkali, so that the wool regains its original condition.

17. Effect of Mordanting and Dyeing on Wool.—Kapff made some experiments on the weakening of wool in the dyeing operations. The dyeing was carried out on the wool in the form of slubbing which was then spun into yarns of which the tensile strength was tested. His results were as follows:[1]

	Kilos.
1. White wool	2.595
2. Wool dyed medium indigo blue	2.603
3. Wool dyed deep indigo blue	2.581
4. Wool dyed indigo and alizarine (0.9 percent of bichromate and 1.2 percent of formic acid)	2.315
5. Wool chromed 2 percent bichromate	1.878
6. Wool chromed 1 percent bichromate	1.979
7. Wool dyed with alizarine (mordanted with 1.5 percent bichromate and 2 percent of formic acid)	2.179

In addition a series of tests were carried out for measuring the resistance of the samples to twisting, with the following results:

	Turns.
White wool	385
Indigo medium	345
Indigo deep	320
Indigo and alizarine	245
Wool mordanted as No. 7	105
Wool dyed and treated with 2 percent of bichromate and 2 percent Monopole soap	80
Wool as the preceding test without soap	48

[1] Woolen fabrics are more or less tendered by the various operations through which they pass during manufacturing, as these involve more or less deterioration in strength and durability. The mechanical rubbing and stretching, the action of heat and the chemicals employed in dyeing, bleaching and mordanting all contribute to this deterioration of the fiber. While such injury to some extent must of necessity occur, yet it is important that it be reduced to a minimum, otherwise the market value of the goods will be affected. Kapff, Kertesz and Leygert have examined the effect of various mordants and dyes and also of milling on the strength of woolen fabrics, but their conclusions differ in many important details. Kapff states that breakages in spinning are far greater in dyed than in undyed wool, except in the case of indigo; the vat dyes appear to be the least injurious to wool of all classes of dyestuffs. Some claim that wool suffers most in piece dyeing, while others claim that the deterioration is greater if the wool is dyed before being spun. There is a general opinion, however, that machine dyeing tends to the better preservation of the fiber. It is said that much harm is done to wool by the after-chroming process, the chromic acid being free for a comparatively long time and thus acting on the fiber, whereas in previously mordanting the chromic acid is reduced and is harmless. Robson favors the use of the rubbing machine rather than the dynamometer for the testing of woolen fabrics, and this will more truthfully represent the wearing quality and durability of the fiber

Kertesz, however, in analysing these results disputes the correctness of their conclusions, as being in contradiction to the well-known results obtained in practice. Kertesz made rather extensive experiments in this connection and his results are shown in the following table:

	Breaking Tests of the Worsted Yarns 52/1 Treated in Form of Cops.		Breaking Tests of the Worsted Yarns 30/2.	
	Breaking Strain at Kilos.	Elasticity in Cm.	Breaking Strain at Kilos.	Elasticity in Cm.
No. 1. Undyed Wool				
Raw Yarn.	37.18	10.66	48.10	14.58
No. 2. Treated with Bisulfate of Soda				
Wet the cops for 20 minutes at 50° C., then add 10 percent bisulfate of soda to the fresh bath; raise the temperature from 40° to 95° C. in ½ hour, treat for ½ hour at 95° C., and then rinse with cold water for 10 minutes.	41.86	11.40	55.12	13.36
No. 3. With Formic Acid				
Same as No. 2, with 4 percent formic acid (85%).	41.90	11.40	56.16	13.62
No. 4. Previously Mordanted				
Wet like No. 2. Mordant in a fresh bath with 3 percent bichrome. 2 percent tartar. Commence at 80° C., treat for 1½ hours at 95° C., then rinse same as No. 2.	38.74	10.40	49.84	11.98
No. 5. Previously Mordanted				
Mordanted like No. 4, with 1.5 percent bichrome. 2 percent formic acid 85 percent.	40.95	10.64	52.78	12.50
No. 6. After-chromed				
Wet like No. 2, then treat in a fresh bath with 10 percent bisulfate of soda; commence at 40° C., raise in ½ hour from 40° to 95° C., and treat for ¾ hour at 95° C. Then chrome for ½ hour with 1.5 percent bichrome at 95° C., and rinse same as No. 2.	41.80	10.80	52.69	12.36

	Breaking Tests of the Worsted Yarns 52/1 Treated in Form of Cops.		Breaking Tests of the Worsted Yarns 30/2.	
	Breaking Strain at Kilos.	Elasticity in Cm.	Breaking Strain at Kilos.	Elasticity in Cm.
No. 7. After-chromed Treat same as No. 6, with 3 percent formic acid (85%), then chrome with 1.5 percent bichrome.	42.73	10.20	52.80	12.44
No. 8. After-chromed Treat same as No. 6, with 10 percent bisulfate of soda, then chrome with 3 percent bichrome.	41.60	10.10	51.35	12.68
No. 9. After-chromed Treat same as No. 6, with 4 percent formic acid (85%), and chrome with 3 percent bichrome.	41.56	10.92	52.52	12.88
No. 10 After-chromed Same as No. 8, except that 3 percent Monopole soap are added besides.	43.30	10.78	54.99	13.30
No. 11. Dyed on Previously Mordanted Material Mordant same as No. 4, then dye with Anthracene Acid Black D S N. Commence at 40° C., raise the temperature in ½ hour to 95° C., and dye for 1½ hours at 95° C.; add 3 percent formic acid (85%) in order to exhaust the bath. After dyeing, rinse for 10 minutes.	39.91	11.40	49.23	11.62
No. 12. Dyed on Mordanted Goods Mordanted same as No. 5, dyed same as No. 11.	40.95	10.60	51.35	11.80
No. 13. Dyed on Mordanted Goods Mordanted same as No. 4, dyed with 3.5 percent Anthracene Chrome Blue G; otherwise same as No. 11.	41.34	11.20	51.22	12.46
No. 14. Dyed on Mordanted Goods Mordanted same as No. 5, dyed same as No. 13.	41.34	11.46	52.00	12.76

	Breaking Tests of the Worsted Yarns 52/1 Treated in Form of Cops.		Breaking Tests of the Worsted Yarns 30/2.	
	Breaking Strain at Kilos.	Elasticity in Cm.	Breaking Strain at Kilos.	Elasticity in Cm.
No. 15. Chromed After Dyeing Wet same as No. 2. Dye in a fresh bath with 6 percent Anthracene Acid Black D S N; commence at 40° C., add 3 percent formic acid (85%), raise in ½ hour to 95° C., and dye for ¾ hour at 95° C. Then add 1.5 percent bichrome, treat for ½ hour at 95° C., and rinse.	41.80	10.98	52.15	11.78
No. 16. Chromed After Dyeing Same as No. 15, only dyed with 10 percent bisulfate of soda instead of with formic acid.	41.20	10.90	52.00	12.34
No. 17. Chromed After Dyeing Dyed same as No. 15, with 3.5 percent Anthracene Chrome Blue G, 3 percent formic acid (85%), after-treated with 1.5 percent bichrome.	42.50	10.70	52.39	12.46
No. 18. Chromed After Dyeing Same as No. 17, only dyed with 10 percent bisulfate of soda instead of formic acid.	42.14	10.86	52.20	12.42
No. 19. Chromed After Dyeing Dyed same as No. 15: 6 percent Anthracene Chrome Black F. 4 percent formic acid (85%). 3 percent bichrome.	43.50	10.82	51.06	12.76
No. 20. Chromed After Dyeing Same as No. 19, only dyed with 10 percent bisulfate of soda instead of formic acid.	43.34	10.78	52.00	12.70
No. 21. Indigo Pale Shade Wet same as No. 2, then dye in a fresh bath with Indigo Vat M L B, with the addition of a little ammonia and some glue solution. Dye in one dip for 25 minutes at 50° C., then rinse, sour off with acetic acid, and rinse again.	41.60	11.52	49.34	12.62
No. 22. Indigo, Deep Shade Dyed same as No. 21, with 3 dips.	39.65	10.68	49.02	12.34

18. Mildew in Wool.—If wool is left in a warm place in a moist condition so that the fiber does not have free access to plenty of fresh air, it will soon develop in spots a fungoid growth or mildew. This causes the fiber to become tender and eventually rot. This fungoid growth will develop without any sizing ingredients or other foreign matter being present on the fiber. It rapidly attacks the scales on the surface of the fiber, and then eats into the inner substance of the wool. Under the microscope (see Fig. 77) this fungoid growth appears as two forms: (*a*) Small elliptical cells which adhere to the surface of the fiber and spread out from it; and which seem to colonise especially at the joints of the scales; (*b*) a tree-like growth consisting of several cells joined together and branching off from one another; these grow over the fiber as a kind of filmy integument, and do not appear to corrode the wool as rapidly as the first kind of cells. Mildew is especially apt to develop on woolen material which contains a small amount of alkali, the alkaline reaction probably being favorable to the growth of the fungus. Hence the tendency of wool dyed in the indigo-vat to develop mildew stains.

FIG. 77.—Wool Fibers Attacked by Mildew. (×300.) *a*, Fungus growing in jointed cells, tree-like; *b*, fungus growing in isolated cells. (Micrograph by author.)

Kalman [1] has made a careful investigation of mildew in wool and gives the following summary of his results: (1) Mildew is caused by definite kinds of bacteria; (2) these bacteria are very sensitive toward acids (either organic or inorganic); (3) pieces dyed in acid baths therefore are not liable to develop mildew; (4) if mildew spots show up in such pieces after dyeing, such spots were present in the goods previous to dyeing; (5) mildew develops most rapidly in wool which has been treated in alkaline baths; (6) Indigo Blue is destroyed by the mildew bacteria, consequently such spots show up in vat-dyed blues as white stains; (7) many dyes appear to kill the mildew bacteria, as for example, Methylene Blue, for wool dyed with this color and showing an alkaline reaction will not develop mildew.[2]

[1] *Färber-Zeit.*, 1902, pp. 245, 341, and 377.
[2] See also Schimke, *Färber-Zeit.*, 1892, p. 290.

CHAPTER VII

RECLAIMED WOOL AND SHODDY

1. Recovered Wool.—Besides the natural varieties of wool which find applications in the textile industries we have a large quantity of recovered wool employed as a textile fiber. The recovery of wool fiber from rags and the spinning of shoddy yarns were introduced first into England in 1813, and did not spread to the Continent until about 1850. In 1852 Kober, in Kannstatt, discovered the process of carbonising, and this made possible the recovery of wool fiber from mixed wool-cotton rags and waste.[1]

Shoddy is obtained by tearing up woolen rags and waste (a process known as "garnetting," being equivalent to a coarse carding), convert'ng it back into the loose fiber and spinning it over again, either alone or in admixture with varying proportions of pure fiber or fleece wool. This *artificial wool*,[2] or *wool substitute*, as it is frequently called, is also obtained from rags and waste containing wool and cotton, or even silk; the vegetable fiber being destroyed by chemical treatment, thus leaving the animal fiber to be extracted and used again. On this account it is sometimes known as extract wool. The industry of converting recovered fiber into yarns and fabrics has assumed of late enormous proportions, and nearly all cheap woolen goods contain a high percentage of these wool substitutes in their composition.[3]

[1] Beaumont estimates (1921) that in the United Kingdom there is a yearly consumption of 350,000,000 lbs. of fleece wool, 200,000,000 lbs. of recovered wool (from rags) and 30,000,000 lbs. of noils. The world's wool supply without the addition of the recovered wool would be inadequate to meet the industrial demands. The total supply of fleece wool throughout the world for 1913 was estimated at 2,800,000,000 lbs., of which 1,074,000,000 lbs. were merino, 1,022,000,000 lbs. cross-bred, and 700,000,000 lbs. were coarse wool.

[2] Artificial wool is not a good term for this class of fiber, as the material is not artificial in the sense of being made like artificial silk; it is a real wool fiber and similar to the natural fleece wool in every particular as to composition and nature. It is really a by-product recovered from waste woolen materials and is simply the true woolen fiber taken out of its manufactured form and converted back into the fiber condition again.

[3] Recovered wool is almost entirely employed in the woolen trade and practically none enters the worsted trade. Of the fleece wool consumed in the United States about one-half goes into the manufacture of woolen goods and the other half into

The various classes of reclaimed wools or shoddies and pulled yarn waste are employed in the manufacture of a great variety of fabrics. Beaumont furnishes the following representative classes of cloths:

Group I. Fabrics in which both the warp and filling yarns are made of shoddy, including tweeds, pilots, friezes, napps, meltons, rugs and blankets.

Group II. Fabrics having a cotton warp crossed with a mungo or shoddy filling yarn, including face-costume cloths, beavers, raised-pile fabrics, figured rugs and decorative fabrics.

Group III. Fabrics having a worsted warp crossed with a cotton filling (face) and also mungo or shoddy filling (back), including union worsteds, coatings and suitings.

Group IV. Fabrics having a cotton warp crossed with a worsted face yarn and a mungo or shoddy backing yarn, including union worsteds, dress and mantle cloths.

Group V. Fabrics compound in structure and made of various counts and qualities of yarns, including union compound-make cloths, reversibles and lined overcoatings.

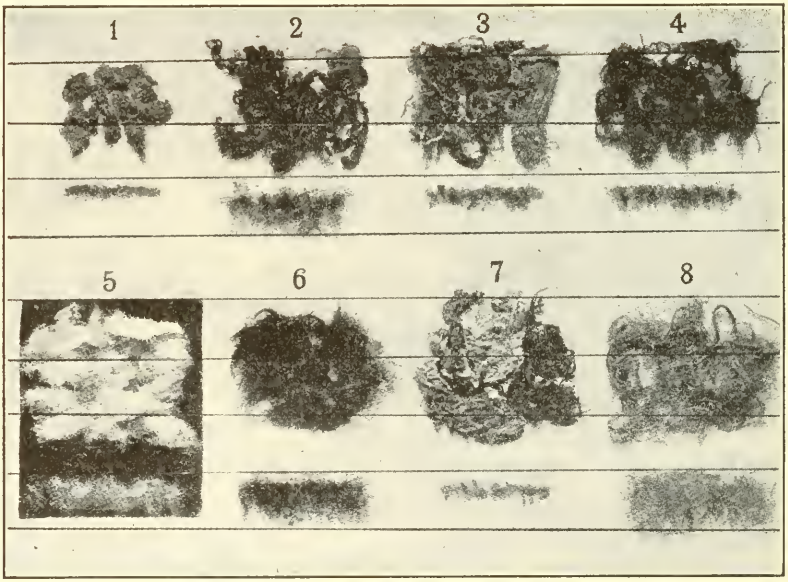


Fig. 78.—Various Kinds of Shoddy: (1) Mungo; (2) shoddy from black stockings; (3) from knitted fabric; (4) from dyed cheviot; (5) from angalo waste; (6) black extract wool; (7) silk waste; (8) from pulled alpaca oil bags. Lines 1 inch apart. (Tetley.)

2. Classification of Recovered Wool.—Depending on its source of production, recovered wool will vary largely in its quality, and according to its origin and nature it is classed under several names. Beaumont states that there are obviously two general classes of recovered wool

worsted goods. Besides this the woolen industry uses about 25 percent of recovered wool, while the worsted industry uses only about 1 percent.

products, as follows: (*a*) the fiber resulting from cast-off clothing and worn-out domestic fabrics described loosely as rags, in which are also included tailors' clippings, remnants and bits of new cloth; and (*b*) the fiber resulting from the waste made in manufacturing processes of spinning and weaving. The second class is known as soft material, not having been previously made into woven or knitted textures.

Reclaimed or recovered wool comprises shoddies, mungos, waste, extract, noils and flocks, and may be broadly classified as follows (Beaumont):

1. Mungoes, from old and new rags of a fulled or firm structure.
2. Shoddies, from serges, cheviots and flannels, scarfs, stockings and knitted goods.
3. Extract, from woolen and worsted fabrics partially made up of cotton.
4. Noils, a by-product in the production of wool-combing.
5. Waste from carding and spinning.
6. Waste from warping and weaving.
7. Flocks or waste recovered from scouring, fulling and shearing.

Barker furnishes the following tabular comparison of different varieties of reclaimed woolen materials:

	Noil.	Mungo.	Shoddy.	Extract.	Flocks.
Sources	Combed wool	Hard woolen and worsted cloths	Soft knitted goods	Hard union goods	Woolen goods
Color and luster	Various, longer fiber lustrous	Various, not lustrous	Various, lustrous	Various, not lustrous	Various
Fineness, ins.	1/400 to 1/1500	1/800 to 1/1800	1/600 to 1/1200	1/800 to 1/1500	1/400 to 1/1500
Length, ins.	$\frac{1}{2}$ to $2\frac{1}{2}$	$\frac{1}{4}$ to $\frac{3}{4}$	$\frac{1}{2}$ to 2	$\frac{1}{4}$ to $\frac{3}{4}$	$\frac{1}{4}$ to $\frac{1}{2}$
Appearance	Open and flaky	Matted and threaded	Fairly open and fluffy	Fairly matted and thready	Curly and fluffy
Handle	Fairly soft	Soft	Soft	Harsh	Fairly soft

3. Shoddy.—Though this name is frequently applied to all manner of recovered fiber, it is more specifically used to designate that which is derived from all-wool rags or waste which have not been felted, or only to a slight degree, also from knit goods, shawls, flannels, and similar fabrics; also yarn and fabric waste from manufacturing processes. These materials are known in trade as "softs." They yield the best quality of fiber, the average length of which is about 1 in., while the variation in length is from 1.4 to 0.2 in. In many cases it is equal in quality to a fair grade of fleece wool, and is used in the production of many high-

grade fabrics. Shoddy is occasionally spun up alone into rather coarse counts of yarn; but it is more often mixed with fleece wool and manufactured into a variety of average grade yarns.

For the manufacture of shoddy from rags the material is first sorted with reference to the following points: (*a*) whether pure wool or mixed fibers; (*b*) for kind of fabric, whether knitted or woven, fulled or unfulled; and (*c*) according to color. Then buttons, hooks, and trimmings are clipped off. The rags are then purified from dirt by treatment in a machine known as a "shaker," or by scouring in a washer. After cleaning, those rags which contain cotton or other vegetable fibers must be carbonised.[1] At the present time small establishments employ sulfuric acid for this purpose, but larger works use hydrochloric acid gas in a special form of apparatus. After carbonising the rags are neutralised, washed, dried, and are passed through willows to dust out the decomposed vegetable matter, and then through garnetting machines to tear the rags up into the fiber form.

4. Mungo.—This refers to the fiber[2] obtained from woolen material which has been fulled or felted considerably; to disintegrate the rags the fibers must be torn apart, and consequently it yields fibers of shorter staple and less value than the preceding. The length of fibers in mungo varies from 0.8 to 0.2 in.; and on this account is never worked up alone into yarn, but is mixed with new wool or cotton and generally spun into low counts of filling yarn. Since mungo consists of a fiber which has already been heavily felted, it is easy to understand that it will have lost much of its capacity for further felting.

Beaumont points out that the quality and make of the fabric, whether worn or unworn, determines the quality of the mungo or shoddy obtainable by rag grinding. Fabrics of the beaver class, made of fine, short wools, yield a good sound mungo; fabrics of the tweed class, made of medium stapled wools and strong in fiber, yield a springy or soft-handling shoddy. Serge and flannel would give two varieties of shoddy, the one of a full, flexible character, and the other of softer and finer staple, but both of satisfactory spinning, fulling and finishing properties.

5. Extract Wool.—This is obtained from mixed wool and cotton rags and waste, and has to undergo the process of carbonisation, whereby the vegetable fiber is destroyed. This process is generally carried out by steeping the rags in a solution of sulfuric acid (6° Tw.) at 140° to 180° F. and then drying, whereupon the vegetable fibers are decomposed and are

[1] See Schwartz, *Färber-Zeit.*, 1908, p. 66.

[2] Beaumont gives the following interesting derivation of the word "mungo." Samuel Parr, of Batley, in 1834 carried out experiments in rag pulling, and from the resultant material he made some goods which were offered for sale at Ossett, near Wakefield. One buyer observing "I daart it winnot goa," Parr replied, "Winnot goa? It mun goa." From this assertion the term mungo was derived.

easily dusted out by willowing, the wool fibers being scarcely affected. The excess of acid is then removed by treatment with soda ash and washing. The fibers obtained are sometimes over 1 in. in length. Extract wool is some called alpaca, and varies much in its length of staple and other qualities.

In the acid treatment of rags, for the removal of the excess of acid, hydroextracting is preferable to passing through squeeze rolls, as the rags are left in a freer working condition. The drying is sometimes done by conveying the rags over steam cylinders heated to 260° to 300° F., but if this is done the rags must be rapidly passed through the machine or the wool will be made brittle. When ordinary drying apparatus is used the temperature is generally run at 210° F. At this temperature the acid

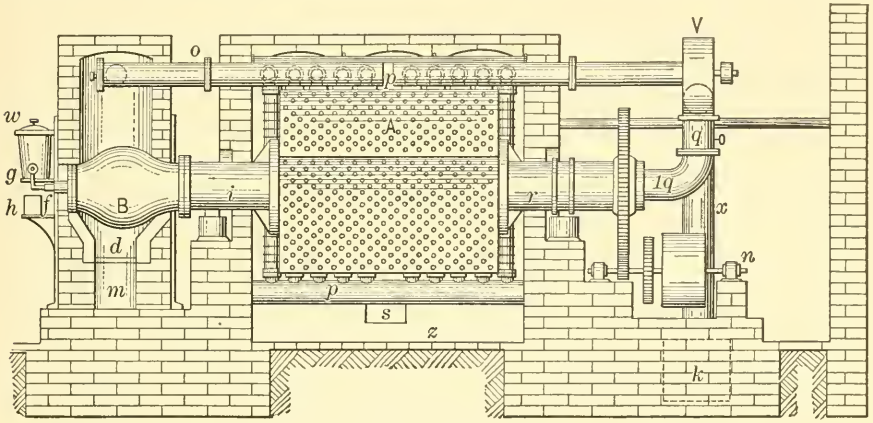


FIG. 79.—Carbonising Machine for Hydrochloric Acid Gas. *A*, Revolving drum for rags or material to be treated; *B*, retort located in furnace for generating gaseous hydrochloric acid.

becomes concentrated and its action on the vegetable substance is to turn it black and reduce it to a charred or " carbonised " condition.

The sulfuric acid treatment has gradually given place to the more modern hydrochloric acid gas method of carbonising. The important factors in favor of this process are its convenience and simplicity, and it enables the carbonising to take place at a lower temperature so that the softness and luster of the wool fiber is better preserved. It also allows of the rags being treated in the dry condition, which is beneficial to the good properties of the wool, for in the older sulfuric acid method, where very thorough washing had to be done after the acid treatment, the wool was liable to be much damaged and felted. The apparatus employed for gas carbonising is usually a large drum or cylinder revolving in an enclosed chamber (Fig. 79). Accessory apparatus is provided for generating and supplying the hydro-

chloric acid gas, which passes through the rags and brings about the carbonisation of the cotton. Or the rags may simply be treated with the gas on tables in an enclosed chamber, or in trucks (as in Fitton's form of apparatus). After treating with the hot gas the rags are run through a machine known as a " wincey," which is a centrifugal machine to shake out the dust from the rags. The rags then pass to the " shaker " machine and finally to the grinder.

6. The Carbonising Process as Related to Wool.—Though the process of carbonising really consists in the action of acids or acid substances on cotton (or other vegetable matter) with but little chemical action on the wool fiber, nevertheless it is the wool that is desired as a product of this process, and as the good qualities of the fiber depend to a great extent on the conditions of the carbonising operations it is proper to consider this process as one relating in a commercial and manufacturing sense to wool rather than to cotton.

The carbonising process of late years has been much extended in the woolen industry beyond that of recovering wool fiber from rags, as in the production of shoddy. Many varieties of loose fleece wool, after being scoured, are carbonised, before undergoing further manufacturing operations, for the purpose of purifying the fiber from all vegetable matter and burrs. In finishing operations a carbonising treatment is frequently given to cloth for the same purpose, and this often is true for the highest grades of fabrics where it is desirable to remove every trace of vegetable impurity.

7. Sulfuric Acid Process.—In carbonising with sulfuric acid there are several features to be observed to get good results with the least injury to the wool fiber, it being understood, of course, that in any carbonising operation the vegetable fiber must be completely destroyed. One of the most important factors in the process is the proper control of the temperature. According to Ganswindt, as far as the wool itself is concerned, a temperature of 176° to 212° F. answers the requirements of the carbonising process. If the wool is impregnated with weak or concentrated solutions of sulfuric acid at a temperature within these limits, it becomes intimately combined with certain proportions of sulfuric acid so that the acid cannot be removed from the wool even by repeated rinsing. The sulfuric acid does not weaken the wool fiber in the slightest degree. The combination of the acid and the fiber is so stable that it is not affected when the wool is subjected to damp heat for an hour or more. It is, however, sensitive to dry heat, the tendering of the wool taking place either (1) by the action of the sulfuric acid on the wool fiber at a dry heat, or (2) by the action of a high temperature on the wool, irrespective of the sulfuric acid. The Lasbordes process, employs a very weak solution of sulfuric acid and a carbonising temperature of 122° F., but such a low temperature will not

answer for carbonising. Reinartz has shown that under certain conditions complete carbonising will result at a temperature of 131° F. He recommends, on the strength of his experiments, that the piece-goods be immersed in a warm solution of the carbonising agent, and then dried on a tentering machine at 131° F. Even at this moderate temperature a large number of the burrs and seeds are carbonised, the remainder being readily crushed, this being proof that with a 2° Bé. solution of sulfuric acid it is not necessary to raise the temperature above 131° F.[1]

After drying the carbonised wool at a high temperature, the next process is dusting. This is purely a mechanical process, and the object is to remove the carbonised vegetable material from the wool. In the case of loose wool, dusting may sometimes be omitted, as the carbonised burrs and seeds are removed by the preparatory processes, picking, and carding.

The material, after dusting, consists of wool impregnated with dilute acid,[2] as the wool fiber remains merely saturated with the acid at a temperature of 180° to 212°, when the vegetable substances are carbonised at that temperature. The object of the neutralising process is to remove the acid remaining in the wool. For this purpose the wool is treated in a solution of soda. Under ordinary conditions the treatment of wool in a solution of soda would not be entirely harmless; but in the case of carbonising the wool is loaded with sulfuric acid, which prevents injury to the fiber by the soda. A soda solution of 3° to 5° Bé. is used. The presence of acid in the wool may also cause trouble in the subsequent process of dyeing, as the wool carrying acid will take a different shade from that taken by wool free from acid.

The strength of the soda solution must be determined by experiment in each case. The acid combines with the alkali to form sulfate of soda. The amount of alkali needed thus depends directly on the quantity of acid in the wool. The best plan is to determine the exact quantity of acid present by testing 1 to 2 ozs. of the wool. It is as important to avoid leaving an excess of alkali in the wool as it is to remove all of the acid, because the alkali attacks the wool fiber. The right quantity of alkali to be used is determined by tests with litmus paper.

[1] The impregnation of the material with the dilute acid liquor should take place at normal room temperature, as under these conditions it is claimed that the cotton will rapidly absorb the acid, while the surface of the wool only will be coated with the liquid, as a result of which the acid will not penetrate to the interior of the wool fiber. By carefully carrying out the operations, the wool can be left with only a trace of the acid, while the vegetable material is thoroughly saturated.

[2] The concentration of the acid in the wool after heating and dusting is a matter of conjecture. Reiser and Spennrath (*Handbook of Weaving*) state that the acid in the wool is concentrated at the most to only 5° Bé. But their conclusions are based on improper chemical assumptions. There is every reason to believe that the acid is present in a rather highly concentrated form.

Sometimes the neutralising process is carried on by rinsing the wool for half an hour in cold water, then extracting and afterwards immersing in the soda solution. It is not clear what advantage is gained by this method. Possibly the object is to economise in the use of soda. This, however, is a mistake, because, as already stated, sulfuric acid is not removed from carbonised wool by rinsing it in water. Warnings appear in technical literature in regard to the rinsing in water. It is stated that drops of water falling on a piece of carbonised goods that has not been neutralised will cause a tender spot in some cases, and may result in a hole.

The wool in which the acid has been completely neutralised must now be treated to remove all traces of glaubersalt or free soda remaining on the fiber. This is done by repeated rinsing in clean water in the rinsing bowl of an ordinary scouring machine or in a special rinsing machine (see Fig. 80). The wool is rinsed in the clean water that enters the bowl, and the soda-laden water passes through the perforations in the false bottom. This rinsing completes the carbonising process. The wool is dried at a moderate temperature, and is then ready for manufacture into yarn.

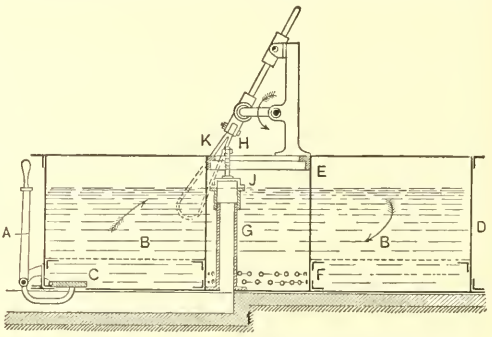


Fig. 80.—Special Rinsing Machine for Carbonised Wool.

8. Gas Process with Hydrochloric Acid.—The solution of hydrochloric acid gas in water, which is known commercially as hydrochloric or muriatic acid, is not suited for carbonising purposes. The dilute solution of muriatic acid when heated exerts more injurious effect on the wool fiber than does dilute sulfuric acid. The effect of hydrochloric acid gas is very different. The use of this gas for carbonising was first mentioned in a German patent in 1877 issued by C. F. Gademann. About the same time Delamore Fils et Cie., Elbeuf, France, carbonised wool with hydrochloric acid gas. From the chemical standpoint carbonising with hydrochloric acid gas is the basis for carbonising with chloride of aluminium or chloride of magnesium.

The process and apparatus required for carbonising with this gas are very different from those used with sulfuric acid. Soaking in the acid, extracting, and preliminary drying are dispensed with. Owing to the suffocating character of the gas it is necessary to enclose it in a tight cylinder from which the air has been partially removed. The muriatic acid gas is introduced into the chamber, and the temperature raised to 210–230°. At the end of two hours the wool is carbonised. Cold air

is then introduced into the chamber, and the acid fumes removed by a fan.

9. Use of Aluminium Chloride.—Carbonising with aluminium chloride is based on the fact that this salt is readily dissociated with formation of free hydrochloric acid, consequently the action is very similar to that

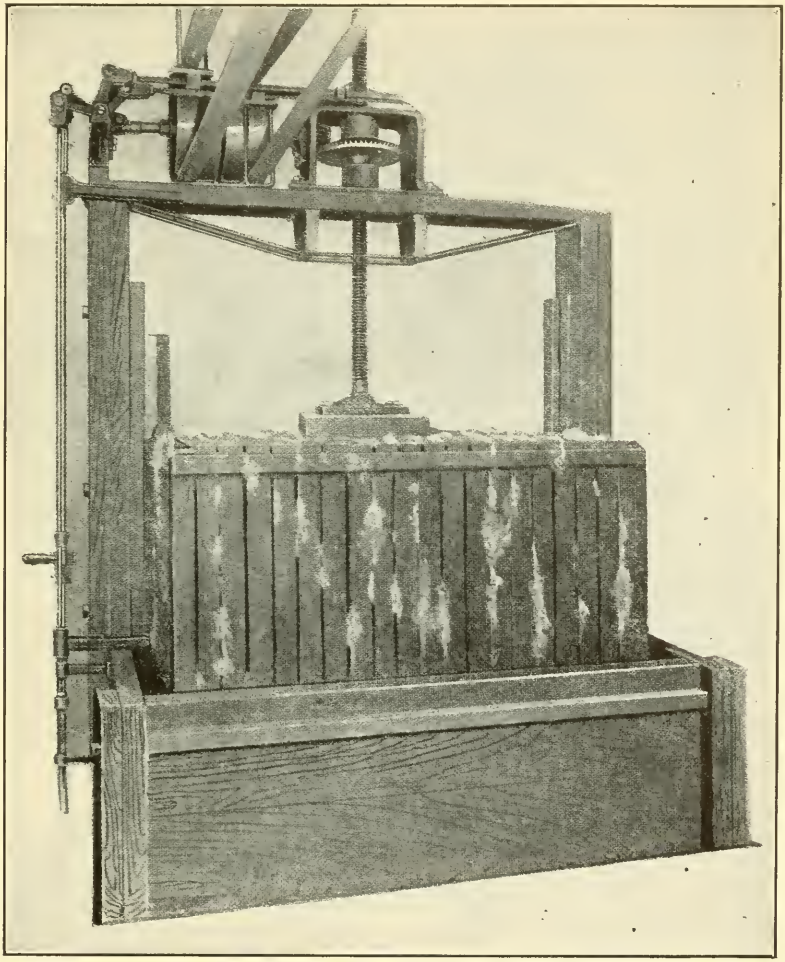


FIG. 81.—Carbonising Machine for Wool Stock or Shoddy. (C. G. Sargent.)

of the preceding method. This process is said to have been discovered by Romain Joly at Elbeuf in 1874, after efforts had been made for years to find some process of carbonising that would have less effect on the wool fiber than had the sulfuric acid process.[1]

[1] It is recorded, however, that Stuart, in 1872, carbonised wool with aluminium chloride; he received a British patent in 1869 for a process of carbonising wool with a solution of aluminium sulfate and common salt.

Carbonising with aluminium chloride has been extensively adopted, although it is more expensive than the sulfuric acid or hydrochloric acid processes. The process of carbonising with this reagent is similar to that of carbonising with sulfuric acid. The wool is immersed in a 7° Bé. solution of aluminium chloride. The wool and pieces are left in the solution for one hour, then extracted and dried, after which the temperature

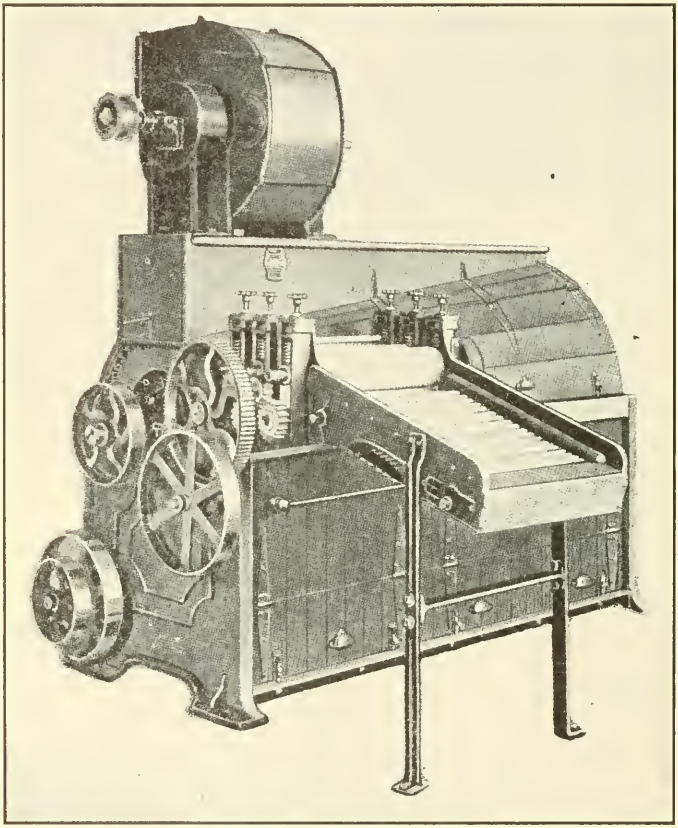


Fig. 82.—Carbonising Duster for Wool Stock and Shoddy. (C. G. Sargent.)

is raised to the carbonising point. The pieces can be dried on a frame or tenter-bars before carbonising. While it is necessary to heat the solution to 180°–212° F. when using sulfuric acid, the wool must be heated to 280° when chloride of aluminium is used, this temperature resulting in a separation of the salt into aluminium hydrate and hydrochloric acid gas.[1]

[1] There has been much difference of opinion as to the carbonising action of aluminium chloride. Frezone claims that aluminium chloride is decomposed at high temperatures, releasing muriatic acid, which is the real carbonising agent. Joly, on the other hand,

The wool fiber is not affected as much by carbonising with chloride of aluminium as with sulfuric acid. This is only natural, as muriatic acid, according to the general opinion, is the carbonising agent, and comes in contact with the wool fiber in the form of a gas; also because of presence of alumina, the effect of the acid on the fiber is reduced.

Wagner has given as his opinion that the alumina with the hydrochloric acid gas serves to protect the color against injury. This explains why carbonising with aluminium chloride has so slight an effect on the colors. This absence of injury to colors proves that carbonising with aluminium chloride produces a different effect from carbonising with hydrochloric acid, and that the claim is unfounded that carbonising with aluminium chloride is the same as with hydrochloric acid. Breinl and Hanofsky have shown that a decomposition of the aluminium chloride does not take place on the fiber.[1] This conclusion is undoubtedly correct, as the alumina can be

claims that the aluminium chloride is the carbonising agent, this being shown by the fact that free muriatic acid injures fugitive colors, a result which does not take place when carbonising with aluminium chloride. The general opinion now is that in carbonising with aluminium chloride the carbonising agent is free hydrochloric acid. There is a difference of opinion, however, regarding decomposition of the compound. Most authorities state the chemical action as follows:

$$Al_2Cl_6+6H_2O=6HCl+Al_2(OH)_6.$$

Georgievics claims that oxychloride of aluminium is left on the fiber as a result of the partial decomposition of the aluminium chloride. He states that only four-fifths of the chlorine is converted into hydrochloric acid, the remainder being left on the fiber in the form of oxychloride. This view, however, has not been substantiated. It is possible that both contentions are sound. The decomposition begins at 230° F. and ends at 266° F., and it is conceivable that at 230° F., and somewhat above that temperature, a basic aluminium chloride is formed according to the following:

$$Al_2Cl_6+3H_2O=3HCl+Al_2Cl_3(OH)_3,$$

and that only when a temperature of 257° to 266° F. is reached does the following change take place:

$$Al_2Cl_3(OH)_3+3H_2O=3HCl+Al_2(OH)_6.$$

The belief that the decomposition is divided into two phases is strengthened by the fact that aluminium chloride remains on the fiber in the form of an anhydrous salt, which is evaporated and decomposed by slowly raising the temperature above 212° F., and that decomposition begins only at 230° F. Meyer states that carbonising by the direct action of the aluminium chloride can take place only when a compound remains on the fiber in an anhydrous state. "As chloride of aluminium when its water content is evaporated decomposes into alumina and muriatic acid, this decomposition may take place also during the carbonising process. In that case the alumina must become fixed on the fiber, while the liberated muriatic acid gas must have the same injurious effect on the colors as results from the older method of using the acid. The strong affinity of the wool fiber for alumina makes it probable that such a decomposition would be promoted by the presence of the wool."

[1] There are certain cases in which carbonising with aluminium chloride exhibits the same effects as carbonising with acid. Breinl and Hanofsky state that these

rinsed from the wool with water, showing that the alumina is not fixed on the fiber.

10. Use of Magnesium Chloride.—This salt is somewhat similar to aluminium chloride in being rather easily dissociated on heating with liberation of free hydrochloric acid. According to Ganswindt carbonising with chloride of magnesium was first mentioned in a patent obtained by A. Frank of Charlottenburg, in 1877. Frank stated that the use of this material for carbonising was possible by reason of its decomposition into hydrochloric acid and magnesia.[1] He recommended that the chloride solution be made up at 5° or 6° Bé., but later experience has shown that this strength is too low and that better results are obtained at 9° or even 13° Bé.

The material to be carbonised is impregnated with the solution, dried, and then exposed to a high temperature at which the vegetable matter is carbonised. The decomposition of the magnesium chloride is similar to that of aluminium chloride and requires a high temperature. Aluminium chloride can be decomposed at 200° to 250° F., while magnesium chloride requires 250° to 300° F. The goods must be free from soap and fatty

conditions are found when the wool, after being soaked in a solution of aluminium chloride is not dried sufficiently or is sprinkled with water before the temperature is raised to 250° F. This interesting fact proves that before the carbonising action begins, the solution of aluminium chloride must be at a certain concentration, which results from the preliminary drying. Very little is known regarding the necessary degree of concentration. It happens that a solution standing at 7° Bé. contains by weight 7 percent of anhydrous aluminium chloride and 93 percent of water. In order to decompose this 7 percent into hydrochloric acid and alumina 21 percent of water is necessary. This concentration corresponds to a 25 percent solution of aluminium chloride standing at 24° Bé.

[1] Frank gives the following formulæ for the chemical action:

$$MgCl_2 + H_2O = MgO + 2HCl;$$

or

$$MgCl_2 + 2H_2O = Mg(OH)_2 + 2HCl.$$

It is doubtful, however, whether the separation takes place according to these formulæ. Such a separation would require a temperature higher than the wool fiber could stand. At a temperature of from 270° to 290° F. magnesium chloride parts with only about half of its chlorine in the form of hydrochloric acid, the residue not magnesia, but a basic chloride of magnesium or oxychloride, according to this formula:

$$MgCl_2 + H_2O = Mg(OH)Cl + HCl.$$

Whether the residue is solely a basic chloride of magnesium or an oxychloride remains uncertain. The latter is possible, because magnesium chloride readily changes to oxychloride. From what has been said it is also apparent that when carbonising with magnesium chloride, what remains on the fiber is not magnesia or magnesium hydroxide, but is either a basic chloride or an oxychloride. This is an important point, because the formation of magnesia or magnesium hydroxide would not be without influence on the wool. The alkalinity of this substance is so great that it would have great influence on many colors.

materials before being entered into the solution, otherwise magnesium soaps will be formed, which are later burnt into the fiber by the high carbonising temperature. The vegetable matter begins to be carbonised at 245° to 265° F., but at this temperature the process is so slow that it has been found necessary to raise the temperature from 280° to 300° F. Above this point there is danger of injuring the fiber and making it yellow.

Tests by Breinl and Hanofsky show that the carbonising action takes place only when the temperature rises above 270° F. A temperature of from 270° to 300° F. is sufficient. Above that the effect on the wool is questionable. These writers assume that the magnesium chloride separates readily into hydrochloric acid and magnesia, and they draw this conclusion from the alkaline reaction of the carbonised goods. On the other hand, it should be stated that the basic chloride or oxychloride gives a basic reaction, and Georgievics points out that this at times can be so strong as to injure the wool fiber.

After carbonising, the basic chloride of magnesium or oxychloride is removed from the wool. The oxychloride of magnesium is more or less soluble in water, the solubility decreasing with an increase in the alkalinity of the oxychloride. The less alkaline the oxychloride, the more necessary is it to use pure water for rinsing. The more alkaline the oxychloride, the more necessary is a souring with dilute hydrochloric or sulfuric acid.

11. Comparison of Carbonising Methods.—There has been much discussion in the technical literature as to the *pros* and *cons* of the various methods of carbonising, taking into consideration the cost, the efficiency of removal of the cotton or other vegetable matter and the liability to injure the wool. There is probably no question but that the sulfuric acid process is the lowest in cost, and under proper conditions it does not appear to injure the fiber or the machinery. It is well suited to raw stock and piece goods. Its chief disadvantage is its bad effect on colors, though this may usually be overcome by neutralising the material with soda. Another advantage of the sulfuric acid process is the low temperature (180° to 212° F.) at which the carbonising takes place, as this preserves the wool in a better condition.

The hydrochloric acid gas process, though without doubt somewhat more costly than the foregoing, has the advantage of not injuring many colors that the sulfuric acid process destroys. One disadvantage of the hydrochloric process is that it requires certain special apparatus, and furthermore it is necessary to use extreme care in preventing the fumes of the acid from escaping into the room or other parts of the mill, as these fumes are exceedingly corrosive and will damage any metal parts with which they come in contact. When efficiently installed, however, the hydrochloric acid process recommends itself strongly to the carboniser, and is being used at the present time to a considerable extent.

The processes involving the use of aluminium chloride of magnesium chloride do but very little damage to the colors on the stock. On the other hand the actual carbonising with these salts does not take place until a comparatively high temperature has been reached, therefore the process necessitates a larger consumption of heat, and there is also the danger of the fiber being overheated and becoming discolored, which of course will also affect the appearance of the dyed color. Another disadvantage to consider is the presence of the metallic oxychloride or hydroxide in the fiber. The chief difference between carbonising with aluminium chloride and magnesium chloride is that the reaction of the treated wool in the first case is acid while in the second case it is basic; and it must be borne in mind that whereas aluminium chloride will not appreciably affect colors that are ordinarily considered as sensitive to acids, yet magnesium chloride carbonising (owing to the residue of basic magnesium salt left in the fiber) will injure many colors that are sensitive to alkalies. Such changes in tone, however, may usually be rectified by a treatment with dilute acid in the rinsing waters.

In former years it was thought that the carbonising process made the wool fiber harsh and brittle and seriously affected its spinning qualities, therefore, wool in the stock was seldom carbonised if such a process could be avoided. It has been shown, however, that by properly conducting the modern methods of carbonising the wool fiber does not become either harsh or brittle and loses none of its spinning qualities. In consequence at the present time a great deal of even the best classes of wool is carbonised in the stock before either carding of spinning, it being considered that this procedure will give a better finished fabric in the long run than would be obtained by putting off the carbonising process until after the pieces were woven and dyed. This also lays to rest the rather popular idea that the carbonising process in the preparation of extract shoddies does great injury to the fiber and therefore that such wool is far lower in value than other forms of wool. Extract wools are no more injured relatively by the carbonising process than are fleece wools, and therefore the acid treatment for the preparation of shoddy cannot be regarded as an injurious process.

12. Flocks.—These are the short waste wool fibers recovered in several of the manufacturing processes through which cloth must pass in finishing. There are two distinct classes of flocks: (1) those resulting from scouring, fulling, raising, brushing, and shearing of woolen or worsted fabrics;[1]

[1] As an interesting point in the "virgin" wool *vs.* shoddy controversy in the various "Truth-in-Fabric" bills, it must be recognised that wool flocks of the first class are "virgin" wool and could be so labeled in garments without deviating from the technical truth. They are just as much "virgin" wool as carded or combed wools, and yet they form one of the lowest grade of "substitutes" to be used in the preparation of woolen fabrics.

(2) those resulting from rag grinding and tearing in the preparation of reclaimed wool. The first class is known as finisher's flocks, while the second is known as rag flocks. Flocks are sorted for the trade into a number of different grades, depending on their origin, quality, and color. Flocks from waste must not be confused with the flocks made from rags and used for the stuffing of mattresses and bedding. These are known as manufactured flocks as they are made in this form intentionally and are not recovered as waste from other operations.

The best class of flocks, which have sufficient length of fiber for purposes of spinning, are blended with better grades of wool and spun into cheap low-grade yarns. The shorter flocks, which are not suitable for spinning, are employed as impregnating or filling material in the felting or fulling of woolen goods. The lowest grades of flocks are used for the making of embossed wall-papers. In the filling of fabrics with flocks in fulling, the cloth may be increased 40 percent in weight by flocking. The flocks are applied at intervals during the soaping of the goods in the fulling machine. In flocking it is important that the cloth should not be run too dry or the flocks may fail to be thoroughly felted into the goods.

13. Other Forms of Reclaimed Wool.—Besides these well-known varieties of recovered wool there are a number of others to be met with in commerce, such as *Thibet wool,* which is usually obtained from light-weight cloth clippings and waste. *Cosmos fiber* is a very low-grade material, usually containing no wool at all, being made by converting flax, jute, and hemp fabrics back to the fiber. *Peat fiber* is a product obtained from partially decomposed peat. It is mixed with wool for yarns to be used in the manufacture of horse-cloths, mats, etc. *Wood-wool* is a somewhat similar product obtained from the long bleached fibers of wood.

Noils may be considered in a certain sense as a form of reclaimed wool, or waste, but strictly speaking this class of fiber is simply the short material separated by combing from the long stapled wool and is not really a recovered waste. Noils cover a wide range of material and qualities, however; the lower grades of noils are often classed in with reclaimed wool or shoddies, while the better grades of noils are to be considered as fleece wool useful as material for the spinning of woolen yarns. The latter class of noils has already been discussed to some extent in the consideration of the wool fiber, and has been classed under botany, merino, and cross-bred noils.

Noils are also obtained from other varieties of hair fibers than the true wool of the sheep. Alpaca noils are of good quality, having a fair staple, and being open, uniform and straight. They are adapted for blending with good shoddy. They are used to develop the so-called " hairy " yarn used in certain classes of fabrics. Mohair noils are used to blend with the better grades of shoddy and certain cross-bred and cheviot wools. Cash-

mere noils are short in staple but extremely soft and are mixed with fine wools. Camel-hair noils are also used.

There is another form of reclaimed wool known as pulled yarn waste. It is a valuable by-product obtained from the waste yarn in spinning, weaving, yarn winding, etc. Like noils, this class of material is a "pure" wool product and furnishes a very good grade of fiber. The yarns are fiberised by treatment in a yarn-pulling machine. Depending, of course, on the character and nature of the original yarn, there will be many grades and qualities of pulled yarn waste. The garnett machine is principally used in recovering the fiber from yarns and the product is often known as "garnetted" waste.

14. Economic Aspect of Shoddy.—A good deal can be said in favor of shoddy and its discriminating use in the manufacture of woolen goods. The word, however, has fallen into rather bad repute and has come to designate material that is imperfect and of low quality. There have been numerous attempts made to pass legislation requiring the proper and distinctive branding of fabrics containing shoddy. As it is probable that about one-quarter of the amount of wool manufactured into woolen fabrics at the present day consists of shoddy, the question is a large and comprehensive one. The aversion toward shoddy, however, is in general rather unwarranted, and the whole subject should be discussed on the basis of the quality of the fiber irrespective of whether it is fleece wool or recovered wool. It has already been pointed out in the consideration of wool that the fleece of the sheep consists of widely varying qualities of fiber, some being of very low grade, imperfect in structure, coarse, short, and of poor quality. There is, in fact, a great deal of high-grade recovered wool which is a far superior grade of fiber to much of that which occurs in the fleece. To require a discrimination between recovered wool and fleece (or "virgin") wool in a fabric, with the purpose of discrediting the former, would work a great injustice, for under such circumstances fabrics could be made from very low-grade fleece wool and yet be classed as of ostensibly better character than fabrics made of shoddy or partly of shoddy. The use of low-grade noils, flocks, and the like would give very low quality cloth, and yet such cloth could be labeled "virgin wool" to the detriment of other cloth of much higher quality that might be made of better class fleece wool mixed with more or less recovered wool or shoddy. The wearing quality and other characteristics of a fabric do not depend so much on whether it is made from fleece wool or from shoddy, but on whether it is made from high-grade or low-grade fiber.

The manufacture of shoddy is a very legitimate and useful industry as it utilises a by-product which would otherwise be wasted, and brings into the market cheap woolen goods for those who otherwise would not be able to wear woolen goods at all. That the use of shoddy, on the other

hand, is abused, and that it is introduced into goods that are misrepresented as being of a higher quality than they really are, there is no doubt; but this is also a tendency in lines of manufacture other than those of the woolen trade.

15. Examination of Shoddy.—Woolen fibers consisting of shoddy sometimes offer a characteristic appearance under the microscope, sufficient, at least, to distinguish them from fibers of new wool. A sample of shoddy generally shows the presence of other fibers besides wool, and fibers of silk, linen, and cotton are frequently to be observed (Fig. 83).

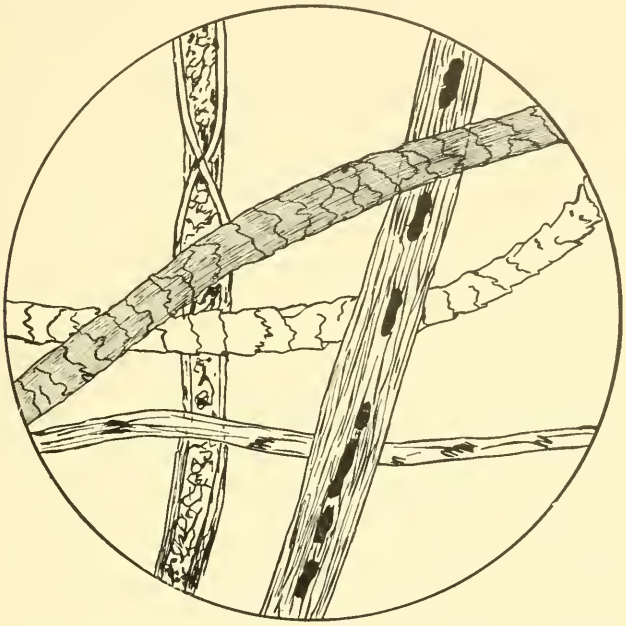


FIG. 83.—Microscopic Appearance of Shoddy, Showing the Varied Character of the Fibers. (×350.) (Micrograph by author.)

Also, the colors of the different woolen fibers present are frequently quite varied, so that shoddy usually presents a multi-colored appearance under the microscope. A very striking appearance, also, is the simultaneous occurrence of dyed and undyed fibers; the diameters of the fibers will also vary between large limits, the variation in this respect being much more than with fleece wool. Some samples of shoddy will also show a large number of torn and broken fibers, and usually the external scales are rougher and more prominent.

The most important characteristic of shoddy, which may be employed in detecting its presence, is the presence of foreign fibers. Fabrics made

from pure fleece wool generally consist of only one kind of fiber, and high-grade fabrics which are made from the best kind of wool should also exhibit a rather uniform diameter of fiber. In no case should such a material composed, for example, of merino fleece wool show the presence of coarse hairy fibers, and the wool going into any high grade of fabric should be so selected as to consist of only one kind of wool, or of those very closely related in their physical characteristics.

However, the different wool fibers in a single fleece exhibit wide variations, and pure fleece wools may be spun together which show a considerable difference in the general microscopical characteristics of the fiber and variations in diameter of the fiber. Although they may determine in some degree the value of a fabric, they cannot be accepted as any sure indication of the presence of shoddy.

It is said that the thickness of wool fiber from one and the same fleece may vary from 0.012 to 0.085 mm., and it is also worthy of note that even in very fine wools there may occur many instances of isolated hairy fibers. These are the stiff-pointed short hairs which occur in certain portions of the fleece, especially around the legs and neck. Therefore these coarse fibers, known also as bristle or beard-hairs, will often be mixed in with even fine merino wool, and they can scarcely be removed in the ordinary processes of carding and combing.

The other grades of wool, such as the domestic-territory wools in mixed blood, are also liable to contain more or less of these coarse beard-hairs, Pure fleece wool may also contain a small amount of vegetable fibers derived from various sources, and their amount may easily extend to about $\frac{1}{2}$ percent. Even small traces of vegetable fibers in fabrics or yarns may be recognised, and in fact their quantity determined, by boiling a weighed sample of the material in a 5 percent solution of caustic soda until the wool is completely dissolved, then filtering through a fine-mesh brass strainer and examining the residue left thereon. In this manner will be found any vegetable fibers that may have been present in the original sample, as these will be unaffected by the caustic soda solution, and by examination under the microscope it will be easy to recognise the presence of cotton, linen, or jute.

It must be borne in mind, however, that pure wool may also show the presence of small quantities of vegetable fibers at times. These often arise from the occurrence of burrs (bristly and barbed seeds of various plants) in the original fleece. South American wools are especially liable to contain such burrs; in many cases these are incompletely removed, and may ultimately appear even in the woven cloth. This frequently explains the existence of short fibers or vascular bundles of vegetable matter in cloth. Isolated fibers of woody tissue and cotton may also accidently creep in through a variety of causes. According to Höhnel,

samples of pure wool may easily contain as much as $\frac{1}{2}$ percent of vegetable fiber. The latter authority also states that the vegetable fibers of shoddy, as a rule, are removed by carbonising; hence the absence of cotton, linen, etc., must not be taken as a criterion to distinguish between pure wool and shoddy. To purify the fabric completely it is necessary to carbonise the cloth so that the vegetable matter may be decomposed, and then the disintegrated fiber is removed by beating and scouring. In case, however, the process of carbonisation has not been resorted to, the presence of vegetable matter may be detected in cloth which has been made from pure fleece wool, and consequently the presence of this material does not conclusively point to the fact that shoddy has been employed in the preparation of the cloth. There will also occasionally be found other fibers of vegetable origin in woolen fabrics, which become accidentally incorporated with the yarn or fabric through a variety of causes, and this is especially true in mills engaged in the manufacture of both woolen and cotton materials or of uniform goods, where the fly from the cotton rooms will often be deposited in the woolen materials in process. Furthermore, shoddy material made from fabrics containing both wool and cotton is nearly always subjected to the carbonising process, whereby all the vegetable fiber is removed, and consequently we may have goods made from shoddy which show entire absence of vegetable fibers, and from this and the foregoing it may be seen that the presence or absence in small quantities of these vegetable fibers is no sure criterion as to whether a fabric consists of shoddy or not. When cotton (always dyed) or cosmos fiber occurs in at least a quantity of 1 percent, this may be taken as an indication of the presence of shoddy, as pure wool would scarcely ever happen to be adulterated with cotton; this only happens by admixture with shoddy wool. Undyed cotton, unless present in considerable amount, cannot be considered as a suspicious component.

Sometimes, however, fleece wool is mixed with cotton for the spinning of yarns possessing certain properties, as in the making of hosiery and underwear yarns even of the better qualities, where the cotton is introduced for the purpose of reducing the shrinking quality of the wool, and also to make a fabric that is " kinder " to the skin, as an all-wool undergarment is usually quite irritating when worn next to the skin. We must also consider the fact that in much cloth we may have a cotton or filling crossed with wool (or worsted) yarns, and the latter may be made entirely from fleece wool. In such cases it would be necessary to limit the examination to the individual yarn rather than to extend it to the fabric as a whole.

The determination of the length of staple is also a rather unreliable indication as to the presence of shoddy, for there are varieties of shoddy wools which are longer in staple then many fleece wools; and also woven

goods, though composed entirely of fleece wool, may show the presence of a large number of short fibers caused by the shearing of the surface of the cloth, and by the tearing of the fibers in heavy fulling.[1]

Where woolen cloth has been impregnated or filled with short fibers obtained from clippings, such may usually be recognised by teasing the sample out with a stiff-bristle brush. Good cloth should not yield over $\frac{1}{2}$ percent of clipped fibers from both sides. When the amount of such fibers is at all considerable, they may be used as serviceable material to test microscopically for shoddy, as they are most likely to be made up of this character of wool. Attention, however, has already been called in a previous page to the fact that these short flocks may consist entirely of fleece (or virgin) wool and therefore could not technically be considered as shoddy.

Fine fleece wools hardly ever show the absence of epidermal scales (though this is frequently the case with coarse wools); hence, if examples of such fine wools are found showing a lack of epidermis, it may usually be taken as an indication of shoddy.

Fleece wool of good quality, when examined under the microscope, nearly always exhibits a distinct epidermis consisting of variously formed scales which appear as serrations on the edge of the fiber. It has been thought that since shoddy, especially the lower grades of this fiber included under extract wool and mungo, has been subjected to severe mechanical

[1] The length of the fiber obtained from a sample of fabric can only be taken in certain cases as indicating the presence of shoddy. The best grades of shoddy may have a longer staple of fiber than some inferior grades of pure fleece wool. This in itself is a disturbing factor, but we must also consider another feature of the case. It is only in good worsted yarn and in knit goods and in loosely woven unsheared cloth that the wool fiber is to be found in approximately its natural length, and it is only in worsted yarn and in knit goods that it is at all possible to pull out from the sample the separate fibers from one another in order to determine their true length. With material made of carded wool this operation is very difficult, and in many cases totally impossible. In full woolen fabrics where the fibers are firmly felted together, and especially if these fabrics have been sheared, as is usually the case, it is impossible to separate the individual fibers in any sample so as to obtain a just estimate of their natural length, as all the fibers taken out of the sample for examination will be broken. Also, due to the shearing, a great number of these fibers will be cut, and when the fabric is disintegrated for purposes of examination, a large quantity of short, broken, and cut fibers will be obtained, it making no difference whether such fibers were originally obtained from pure fleece wool or from shoddy. It also frequently happens that in heavily fulled goods the shearings or short-cut fibers from other cloths are fulled into the fabric under examination in order to increase the body and weight of the latter. Consequently, such fabrics may often contain very short fibers, although these cannot be properly classified as shoddy wool. It is also to be remarked that accurate microscopic determinations of the length of a large number of individual fibers is both difficult and time-consuming. From these considerations it may readily be understood that the determination of the length of fibers taken from a sample of fabric cannot be relied upon to any great extent to ascertain the presence of shoddy.

and probably chemical treatments, the epidermal scales would be more or less removed from the surface of the fiber, and consequently that such wools would show a large number of individual fibers and incomplete epidermis. To a certain degree this is true, but it is also a fact that many grades of pure fleece wool will also show quite a number of fibers having a lack of proper epidermal scales.

Höhnel calls attention to the fact that the following conditions previous to the manufacturing process itself have considerable influence on the good structure and integrity of the wool fiber: Badly cut staple, lack of attention in raising the sheep, poor pasturage, sickness of the animal, the action of urine, snow, rain, dust, etc., packing the wool in a moist condition, rapid and frequent changes of moisture and temperature, the use of too hot or too alkaline baths in scouring, scouring with bad detergents, etc. These influences may lead to the partial removal of the epidermis, and to the softening and breaking of the ends of the fiber.[1] There must also be considered the influence of willowing, carding, combing, spinning, weaving, gigging, fulling, acidifying, washing, shearing, pressing, etc., from which it is easy to understand why even fibers of fleece wool may show the entire absence of epidermis. Höhnel also criticises other alleged characteristics of shoddy,

FIG. 84.—Fibers from Shoddy Showing Torn and Raveled Ends.

[1] This is especially true when dealing with materials made from the longer and coarser grades of wool, for the finer merino wools are more plentifully supplied with a protective layer of wool fat, and consequently the epidermal scales therein are more perfectly protected from injury, and will not show peculiarity of absence of epidermis in any noticeable degree. Also, the merino sheep is more carefully cultivated and cared for, and this has much to do with the complete development and preservation of the fleece. In addition to this, the fine merino has a fiber which is soft and pliable, and consequently is not so easily injured as the stiffer and coarser fibers of the lower-grade wools.

such as torn places in the fiber, unevenness in diameter, etc., claiming that these can hardly be taken as an indication of shoddy because such marks are often regularly present in many fleece wools. Most samples of shoddy, in fact, show scarcely any structural differences from ordinary fleece wool.

It is often impossible to determine by chemical or physical examination if a sample of woven cloth contains shoddy or pure fleece wool only. There are many forms of shoddy (remanufactured fiber) which are composed of wool fibers of excellent quality; such, for instance, as the shoddy obtained from knit-goods, or from tailors' clippings of loosely woven fabrics. It is possible, in fact, to have a fabric composed entirely of shoddy to exhibit a better quality of fiber on examination than a fabric which may be composed of pure (though inferior) fleece wool. It must also be borne in mind that when a fabric is unraveled and teased apart so that an examination of the fibers may be made, the fibers so obtained in reality constitute a form of shoddy, having been previously subjected to the various operations of manufacture. Whereas it is quite possible to definitely decide whether a sample of loose wool (or even yarn) contains shoddy or not, in very many cases it would be impossible to make such a statement regarding a piece of woven cloth from an analysis or examination of the latter. After all, the question as to the use of shoddy in woolen fabrics resolves itself into a question as to the quality of the fiber, irrespective of the fact as to whether the fiber was derived first hand from the fleece or from some other source of manufactured material.[1]

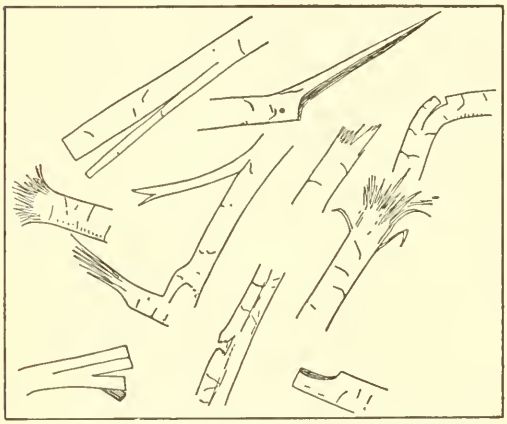


FIG. 85.—Shoddy from Dyed Worsted Clips.

The ends of shoddy fibers, however, usually present a torn appearance; at least there is a great predominance of such fibers in shoddy, whereas in

[1] From all these considerations it may readily be understood that the exact determination of the presence of shoddy in fabrics, even by employing the most skillful methods of scientific investigations, is a very difficult matter, and it is rather foolhardy for anyone not acquainted with the conditions of the problem to attempt to state that shoddy may be definitely found in fabrics, and consequently it is an easy matter to regulate the use of shoddy therein. In a great many cases the only person who would be able to state whether shoddy had been used in a specific sample of cloth or not would be the manufacturer who made the cloth.

fleece wool this appearance is seldom to be observed, the end of the fiber being cut off sharply. The appearance of the torn fibers may be easily observed under the microscope; the epidermis being entirely torn away, as well as the marrow which is sometimes present, while the fibrous cortical layer is frayed out like the end of a brush. This appearance can usually be rendered more distinct by previously soaking the fibers in hydrochloric acid (Fig. 84). Sheared fibers are recognised by being very short and by having both ends sharply cut off.

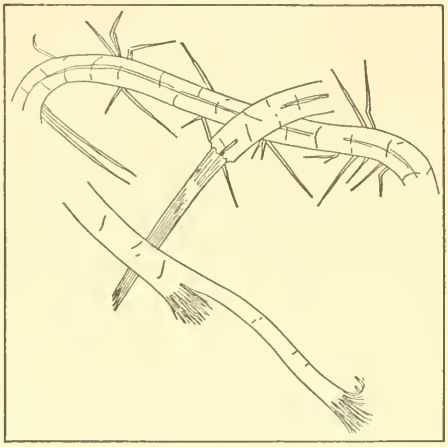


Fig. 86.—Shoddy from Fine Dyed Worsted Clips.

The color of the fibers is also a characteristic appearance of shoddy, as the majority of shoddy is made up of variously colored wools. It is of rare occurrence that rag-shoddy possesses a single uniform color. Hence if a sample of yarn, possessing a single average color, on examination reveals the presence of variously colored fibers, it is almost a positive indication of shoddy. In this connection it must not be forgotten, however, that differently colored wools are frequently mixed together previous to spinning, to make so-called "mixes." As a rule, however, only two to three colors are used together; therefore a purposely mixed yarn of this description is not likely to be confounded with a shoddy yarn where individual fibers of a large number of colors are nearly always shown.

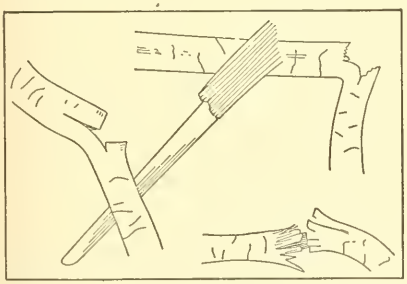


Fig. 87.—Shoddy from Carbonised Brown Serge.

The examination of yarns and fabrics made from shoddy or mixtures of shoddy with fleece wool, is one of the most difficult and interesting problems for the textile microscopist, as it requires a high degree of skill and accuracy coupled with long experience. The differentiation between shoddy and fleece wool fiber is a most delicate and difficult one. This is due to the fact that every individual fiber cannot be definitely recognised as being shoddy or fleece wool, and a single microscopical characteristic does not suffice to distinguish shoddy in a sample. In order to arrive at any just estimate as to the presence of shoddy it is necessary to

conduct many comparative examinations on known samples of material.

One feature of shoddy fibers, which has been put forward as a possible means of detecting their presence, is that they are more susceptible to the action of strong solutions of caustic soda or sulfuric acid than fibers of fleece wool. For observing the behavior of the fibers in this connection, fibers of new wool and those of shoddy are placed side by side on an object glass and a drop of concentrated sulfuric acid is touched to them; the time required for the attacking of the fiber and the structural changes which take place are then noted. Schlesinger has made a number of interesting tests in this connection, and shows that the shoddy fibers are attacked sooner and also to a greater extent than fleece wool fibers. The following table shows some of the results obtained:

Color Changes in Shoddy Fibers.	Time Occupied in the Decomposition of the Outer Scales of the Fibers.			
	Shoddy.		Wool.	
	Mins.	Secs.	Mins.	Secs.
Green to yellow	3	45	4	05
Brown to light brown	3	15	4	15
Violet to colorless	3	15	2	55
Black to red	2	10	4	00
Red to pale red	1	45	6	05
Blue to colorless	1	45	1	25
Yellow to dingy yellow	1	30	3	45
Pink to yellow	1	15	2	20
Black to yellow	1	05	5	10
Deep green to gray	1	05	1	50
Deep yellow to pale yellow	1	00	1	45
Deep brown to orange	1	00	1	15
Light green to colorless	0	45	1	30
Light gray to colorless	0	30	1	10
Colorless	0	15	4	30

While these tests of Schlesinger are interesting they are scarcely conclusive in enabling one to definitely determine the presence or absence of shoddy in a sample of woolen fabric. The character of the tests is so indefinite that even in the hands of a skillful microscopist they cannot yield very accurate results.

L. J. Matos (*Textile World*) gives some interesting drawings showing the torn and corroded appearance of certain grades of shoddy fibers under the microscope. Figure 85 is shoddy made from new, fine, blue worsted

clips. A careful inspection of the drawing shows the great variety of broken ends of fibers, and also the tendency of the fibers to split or to tear lengthwise. There are also shown three fibers with side breaks, which evidently are a result of a tearing action of the shoddy machine. Figure 86 shows a shoddy made from new, fine, black worsted clips, and here again we clearly notice their peculiar terminal fractures where the fiber has been pulled asunder. One of the fibers has a number of "spines" projecting from it. These so-called spines are really the fiber cells, which were no doubt loosened by the tension on the fibers in the machine. It should be noted that both Figs. 85 and 86 represent new wool that has been simply mechanically reduced to shoddy, and not at any time carbonised. Figure 87 is a shoddy made from carbonised brown serge. Here is to be seen what indicates the brittle character of the fiber, devoid of its elasticity. The breaks of the fiber are seen to be quite abrupt. Figure 88 is shoddy made from brown serge that has been carbonised and sub-

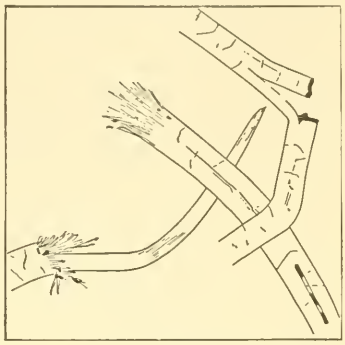


FIG. 88.—Shoddy from Carbonised and Stripped Wool.

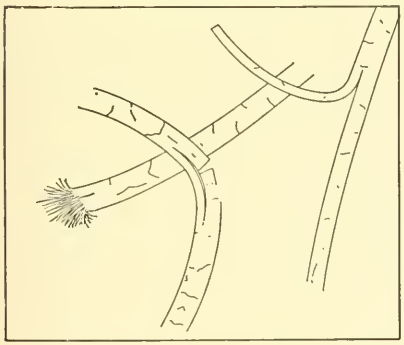


FIG. 89.—Shoddy from Carbonised, Stripped and Dyed Wool.

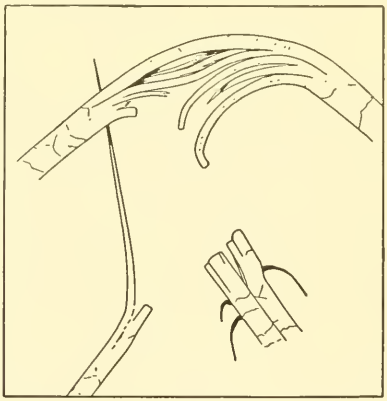


FIG. 90.—Shoddy from Carbonised Wool Dyed Red.

sequently stripped. The abrupt character of the breaks is plainly noticeable, while at the same time the fibrils comprising the body of the wool fiber are very distinct. Their presence may be due to the chemical action of stripping. Figure 89 shows fibers made from blue serge that had been first carbonised, then stripped, and afterwards dyed green. Here again we notice the tendency to break longitudinally, and where

a terminal break occurs the fibrils appear distinctly. Figure 90 is shoddy from the same batch as that shown in Fig. 88, except that it has been dyed a full red. In this figure we notice that one of the fibers has been split longitudinally, while the other three fiber terminals show break characteristics that indicate the brittleness of the stock. Figure 91 was originally a brown serge that had been carbonised, then stripped, afterwards dyed a deep orange, and finally garnetted. A great majority of the breaks of fibers in this sample are extremely abrupt. There appear to be no longitudinal ruptures, and this seems to indicate little or no elasticity.

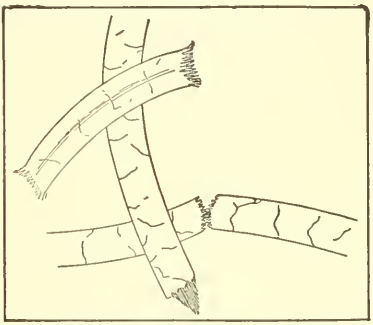


Fig. 91.—Shoddy from Wool Carbonised, Stripped, Dyed and Garnetted.

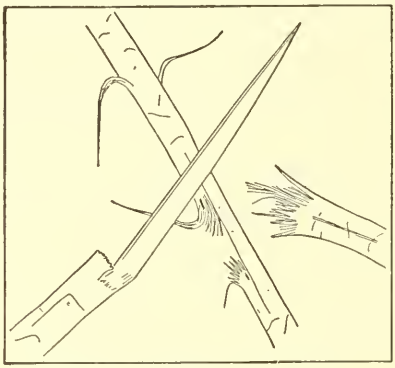


Fig. 92.—Shoddy from Wool Knitgoods.

Even the fibrils do not show plainly. Figure 92 is a shoddy made from various knit goods of different colors that were first carbonised, then stripped, and afterwards dyed blue. Some of the rags came from the dye-bath a purple shade, others a blue-slate, some distinctly blue, while others were quite black. The garnetted stock has a pleasing blue shade, inclining to the red. Referring to the figure, the fibers seem to be mutilated and broken. One fiber shows a rather curious side abrasion, a form of mutilation that appears to be quite common in this lot of shoddy.

CHAPTER VIII

MINOR HAIR FIBERS

1. The Minor Hair Fibers.—Besides the fiber obtained from the domestic sheep, there are large quantities of hair fibers employed in the textile industries and obtained from related species of animals, such as goats, camels, etc. As these are all more or less utilised in conjunction with wool itself, and are subjected to similar operations in manufacturing, it will not be out of place to consider them at this point. The chief among these related fibers are mohair, cashmere, alpaca, cow-hair, and camel-hair.

The following table showing the comparison of the various minor hair fibers is adapted from Barker:

	Mohair.	Alpaca.	Camel-hair.	Cashmere.
Length, ins.	9	12	5	3
Strength	Very strong	Fairly strong	Fairly strong	Fairly strong
Luster	Very high	High	Good	Good
Color	White	Vari-colored	Brownish	Brown and white
Fineness, ins.	1/700	1/800	1/800	1/12000
Handle	Fairly soft	Soft	Soft	Very soft
Form of staple	Straight	Straight	Fairly curly	Fairly curly
Uniformity	Uniform	Uniform	Fair	Fair
Uses	Dress fabrics, linings, upholsteries	Dress fabrics, linings	Dress fabrics	Shawls and hosiery

2. Mohair.—This fiber is obtained from the Angora goat (Fig. 93), an animal which appears to be indigenous to western Asia, being largely cultivated in Turkey and neighboring provinces.[1] The fleece is composed of very long fibers, fine in staple, and with little or no curl. The fiber is characterised by a high silky luster. Mohair is now grown to a

[1] The Angora goat is a species descended from the genus *Capra Ægagrus*, the claimed ancestor of all *Capra Hircus* or domestic goats, inhabiting the hills of Southern Europe and Asia Minor. It is fairly large, and during the warm season grows a short woolly fur of a grayish brown color; this in winter is covered with a larger and brighter hair. There is no record of the early domestication of this goat, but it doubtless existed from the remotest times in Asia Minor, and has for ages produced hair remarkable for its length, luster and fineness.

considerable extent in the Western States, principally Oregon, California, and Texas, the goats having originally been imported from Turkey; there is also a large quantity of mohair grown in Cape Colony. The principal mohair clips (1902) are as follows:

Turkey	8,500,000 lbs.
Cape Colony	7,500,000 "
United States	1,250,000 "

The principal use of mohair is for the manufacture of plushes, braids, fancy dress fabrics, felt hats, and linings. The character of fabric in which it may be employed is rather limited on account of the harsh wiry nature of the mohair fiber, and the fact that it will not felt to any degree.[1]

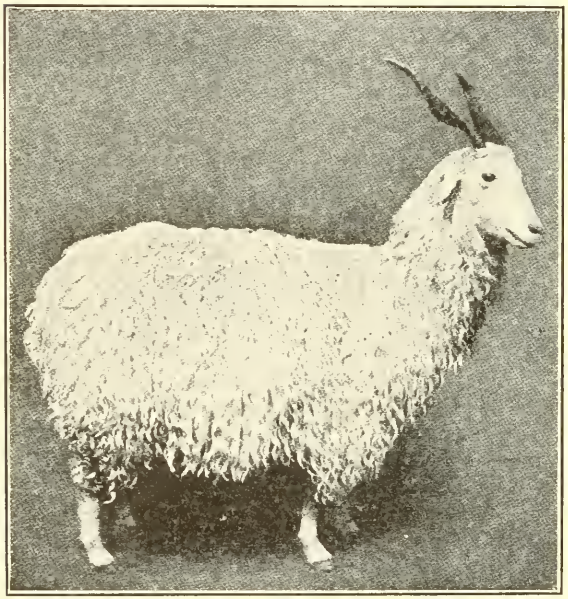


FIG. 93.—Angora Goat.

Domestic mohair (American) has only about two-thirds of the value of the foreign fiber; mohair in general has quite a large amount of kempy fiber (which will not dye), but the domestic variety contains about 15 percent more kemp than the foreign, hence the lower value of the former. Another reason for this lessened value is that foreign mohair always represents a full year's growth (the fibers being 9 to 12 ins. in length), whereas a great deal of domestic mohair is shorn twice a year. This is especially true of that grown in Texas; the hair commences to fall off the goats in that district if allowed to grow for the full year. In judging of the quality of mohair, the length and luster are of more value than the fineness of staple. The finest grades of domestic mohair come from Texas, the

[1] The mohair fiber is harder and stiffer, though more elastic than wool, and it is especially useful for embossed upholsteries and pile fabrics; its luster rivals that of silk and is very permanent in character. Mohair absorbs less moisture than wool, and it does not felt, so should not be used for fulled fabrics. The draping properties of mohair fabrics are excellent, and on account of its high luster the fiber is largely used for the manufacture of braids.

fiber from Oregon and California being larger and coarser. In Oregon the fleece is grown for a full year, and consequently the fiber is very long. The average weight of the fleece from Oregon goats is 4 lbs. while in Texas it is only $2\frac{1}{4}$ lbs. Foreign mohair varies much in quality, depending upon the district in which it is grown; as a rule, the finer varieties are shorter in staple, the finest being about 9 ins. in length. Foreign mohair can be spun to as high a count as 60's, whereas the finest quality of domestic mohair can only be spun to as high as 40's. The coarsest varieties of mohair are used in carpets, low-grade woolen fabrics, and blankets.

In its manufacturing processes the treatment of mohair is practically the same as that of long wool. The fleece possesses several qualities; thus an average fleece would have 36's quality from neck, 40's from shoulders, 36's from middle of sides and back, 32's from haunches, and lower qualities of 28's and under from the edges.

The term mohair, in a general sense, is becoming an extensive one, including the fiber from the fleeces of goats of various crosses with the true Angora.

3. Classification of Mohair.—According to E. W. Tetley (*Textile Manufacturer*) the different kinds of mohair may be classified under the following heads:

Turkey Mohair.—As would be expected from the native home of the Angora goat, Turkey mohair is of the very best, being of good length, excellent luster, and clear color.[1] It is only reasonable to expect that it will become still better in quality, for the methods employed at present in breeding and rearing, in sorting, classing, and packing, leave ample room for improvement on more scientific lines. Different goat districts supply different classes of hair—i.e., Angora, Beybazar, Castamboul, and Van (Fig. 94). The following list will give some idea of their characteristics:

Fine Districts.—Length, 6–7 in.; luster excellent, color very clear, handle very soft.
Beybazar.—Length, 8–9 in.; luster very good, color good, handle soft.
Angora.—Length, 8–9 in.; luster very good, color good, handle soft.
Fair Average.—Length, 8 in.; luster good, color fairly good, handle fairly soft.
Castamboul.—Length, 8–10 in.; luster good, color fairly good, handle fairly soft.

In addition to these standard qualities of mohair, there are various lower grades always on the market—viz.: Good gray, good yellow fleece, locks, ordinary yellows.

[1] Barker states that the quality of Turkey mohair is not what it once was. The deterioration was caused by crossing with the common Kurd goat resulting from an unexampled demand for mohair fiber by Europe from 1820 to about 1860. The Kurd goat yields only a long coarse kempy hair, mostly used for tent and sackcloth. Since 1880, however, the quality of Turkish mohair has much improved by breeding back to the true Angora type.

Barker gives the qualities of Turkey mohair as follows:

	Turkey Fine. Fine.	Turkey Fair, Average.	Turkey Beybazar.	Turkey Castamboul.
Length, ins	6 to 7	6 to 8	7½ to 9	8 to 10
Luster	Very lustrous	Fairly so	Lustrous	Very lustrous
Fineness, ins	1/800	1/400	1/600	1/600
Handle	Very soft	Fairly soft	Soft	Very soft
Appearance	Good color, wavy, clearly defined	Fair color, not clearly defined in staple	Good color, clearly defined in staple	Good color, wavy, clearly fined in staple
Cleanness	Very clean	Fairly clean	Fairly clean	Clean
Uniformity	Very uniform	Uniform	Uniform	Uniform

FIG. 94.—Mohair from Turkey. (1) Fine districts; (2) Beybazar; (3) Angora; (4) fair average; (5) Castamboul. (*Text. Mfr.*)

Van Mohair, drawn from the district of that name in Asia Minor, is dirty and very dry, though it scours up very well, and is specially mentioned in the British Factory Act as a dangerous wool, being more liable than other mohair to contain the deadly germs of anthrax. In fineness, Turkey mohair goes up to about 50's quality.

Cape Mohair.—In spite of many difficulties, the Angora goat was successfully introduced and crossed with the South African variety to produce a breed of goats growing a good class of hair; indeed, mohair from the Cape will now bear comparison with the best Turkish qualities, the climate and general conditions being very suitable.[1] The color of

[1] The Cape Colony at the present day yields about one-half the world's supply of mohair, and the flocks amount to about 4,000,000 goats.

Cape mohair is not generally so clear as Turkey hair, being of a rather deeper brown. There are two clips a year, summer growth and winter growth. The following list shows the principal classes (Fig. 95).

Cape Kids.—The first shear from the young goat, equivalent to lamb's wool. Length, 6–7 in.; very lustrous, brownish color, and very soft.

Cape Firsts.—The long summer growth. Length, 8 ins.; very lustrous, fairly clear in color, and soft.

Cape Winter.—The shorter winter growth. Length, 5 ins.; good luster, fairly clear color, and fairly soft.

Cape Basuto.—A class of hair rather stronger and coarser than Cape firsts.

Cape Mixed.—A class of hair in between Cape firsts and Cape winter, such as a late clip, or a mixture of the two clips.

Thirds.—Equivalent to edges of a long wool fleece. Each fleece may be subdivided into firsts, seconds, and thirds, according to fineness, length and luster.

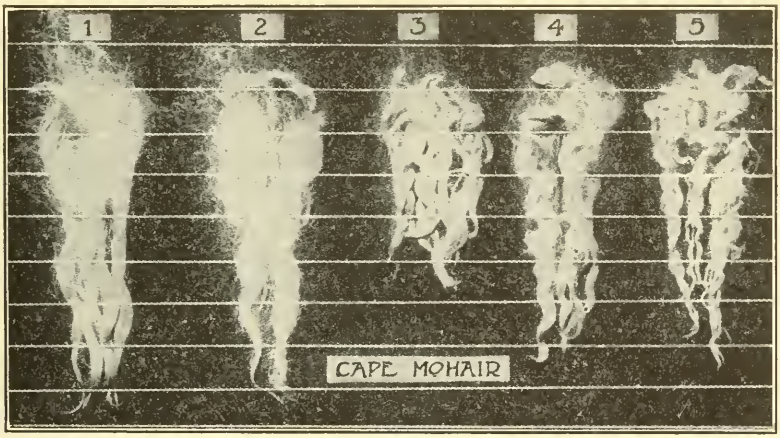


FIG. 95.—Cape Mohair Samples. (1) Basuto; (2) mixed; (3) winter hair; (4) Cape firsts; (5) Cape kids. (*Text. Mfr.*)

From the foregoing it will be seen that Cape kids are the most valuable product, on account of their extra fineness, and because the supply is small. Cape firsts are valuable on account of their good quality, combined with extra length. Cape mohair, in fineness, goes up to about the same quality number as Turkey hair—viz., 50's.

According to Barker, improvement in Cape mohair would be possible if double clipping could be avoided. Clipping the goat twice a year necessarily implies a shorter staple. It is claimed that the double clipping is necessary to prevent the shedding of the fleece. The fineness of fiber of Cape mohair is also not all that could be desired and there is a large proportion of kemps. These defects can only be improved by careful breeding and cultivation. The uniformity of staple is not as good as that of Turkey mohair. Barker furnishes the following properties of the different kinds of Cape mohair:

Type.	Length.	Luster.	Fineness.	Handle.	Appearance.	Cleanness.	Uniformity.
	Ins.		Ins.				
Cape Kid....	5 to 7	Very lustrous	1/800	Very soft	Yellowish color, clearly defined staple	Clean	Very uniform
Cape Firsts..	6 to 8	Very lustrous	1/600	Soft	Fair color, clearly defined staple	Fairly clean	Fairly uniform
Cape Winter.	5	Fairly lustrous	1/600	Fairly soft	Fair color, fairly defined staple	Fairly clean	Fairly uniform
Cape Seconds	5	Fairly lustrous	1/600	Fairly soft	Bluish color, kempy, fairly defined staple	Dirty	Not uniform
Cape Mixed..	4 to 5	Poor in luster	Irregular, coarse	Harsh	Varied; disorganised in staple; strong and "wiry"	Dirty	Not uniform

American Mohair.—Of late the United States growers have much improved the breed of goats, although the manufacturers consider both Turkey and Cape mohair to be worth much more than the domestic types, being more lustrous, less kempy, and possessing superior spinning qualities. Half the total of the United States clip, and the best quality hair, comes from Texas, the rest being supplied by California, Oregon, New Mexico, and other Western States. The goats are clipped twice a year, in spring and fall, owing partly to climatic conditions, and partly because two clips of six months bring more profit than one of twelve months.

Australian Mohair.—The production of mohair in Australia is only slight, and it is unlikely that it will greatly increase for a long time, unless an unexampled demand for the fiber comes about, as Australia is a great wool-growing country. The goat is useful in keeping down scrub, and in quality its hair is good, being of the class of a Turkey average.

Mohair Tops.—In the preparation of mohair for spinning the fibers are combed into tops somewhat in the same manner as long stapled wools. Oil is added as in the case of wool, to the extent of about 2 percent, and as the fiber has a marked tendency to fly about, the oil is useful in keeping the fibers together. Mohair tops are not usually quoted in quality numbers, but as in the following list. The diameters of the fibers of each quality are the average of a large number of tests, and enable their fineness to be compared with the wool tops. The fine white mohair gives measurements corresponding to a 56's quality wool top.

	Diameter in Inches.	
Mohair fine white top	0.00102	1/976
" good medium white top	0.00133	1/754
" medium white top	0.00160	1/626
" ordinary white top	0.00188	1/535

Testing Mohair Tops for Quality and Uniformity.—As in the case of wool tops, judging quality is largely a question of practice, though of course there is not the wide range in mohair tops that has to be dealt with in wool tops. It may be noted here that English luster wool is often mixed with mohair for medium and lower qualities. Mohair, especially the finer sort, is uniform in length, but "draws" may be made from a mohair top of the longest to the shortest fibers, exactly as when testing a wool top for uniformity.

Mohair noils are the short fibers separated in the combing of mohair.

4. Microscopy of Mohair.—Microscopically, the mohair fiber is possessed of the following characteristics: The average length is about 18 cm. and the diameter about 40 to 50 microns, and very uniform throughout the entire length (Fig. 96). The epidermal scales can only be observed with difficulty, as they are very thin and flat, though regular in outline. They are also very broad, a single scale frequently surrounding the entire fiber; the edge of the scale is usually finely serrated. The best grades of fibers show no medulla, but there are usually to be found (especially in domestic mohair) coarse, thick fibers possessing a broad medullary cylinder, thus resembling the structure of ordinary goat-hair, from which, however, they are to be distinguished by being more slender and more uniform in their diameter. Longitudinally, the fiber exhibits coarse, fibrous striations, approximating the appearance of broad and regularly occurring fissures. These striations are usually much more pronounced than those to be found in sheep's wool. Due to the fact that the surface scales lie very flat and do not project over one another, the edge of the fiber is very smooth, showing scarcely any serrations at all, which partially accounts for its

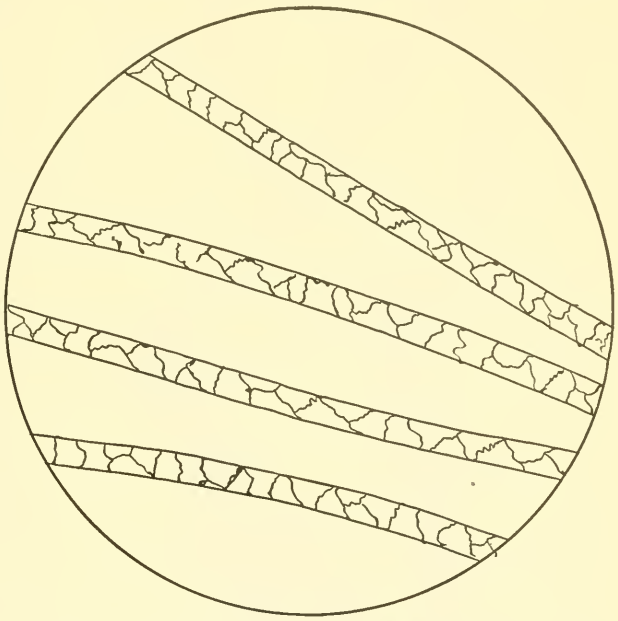


FIG. 96.—Mohair Fibers. (×350.) (Micrograph by author.)

utter lack of felting qualities. The outer end of the fiber is either slightly swollen or blunt, but never pointed. When viewed under polarised light the fibers occasionally show the presence of a medullary canal, which appears as a hollow space, giving an illumination somewhat resembling that of a bast fiber, and covering from one-fourth to one-half of the diameter.

5. Cashmere.—This fiber is obtained from the cashmere goat native to Thibet and the district of Kashmir in northern India. It is characterised by very large horns and the fleece consists of a long, straight, silky fiber, at the roots of which, on certain portions of the body, is to be found a small quantity of very fine wool of brownish color. This latter is the true cashmere of commerce from which the renowned cashmere and Paisley shawls are made. Attempts at cultivating the cashmere goat in other countries have so far failed. Cashmere is remarkable for its softness, and is much used in the woolen industry for the production of fabrics requiring a soft nap. Cashmere is the fiber employed in the manufacture of the famous Indian shawls. There are two qualities of cashmere wool, the one consisting of the fine, soft down-hairs and the other of long, coarser beard-hairs.[1] The former are from $1\frac{1}{4}$ to $3\frac{1}{2}$ ins. in length, 13 microns in diameter, while the latter are from $3\frac{1}{2}$ to $4\frac{1}{2}$ ins. in length by 60 to 90 microns in diameter. The wool-hairs show visible scales but no definite medulla, whereas the beard-hairs possess a well-developed medulla. The cortical layer is coarsely striated and shows characteristic fissures.

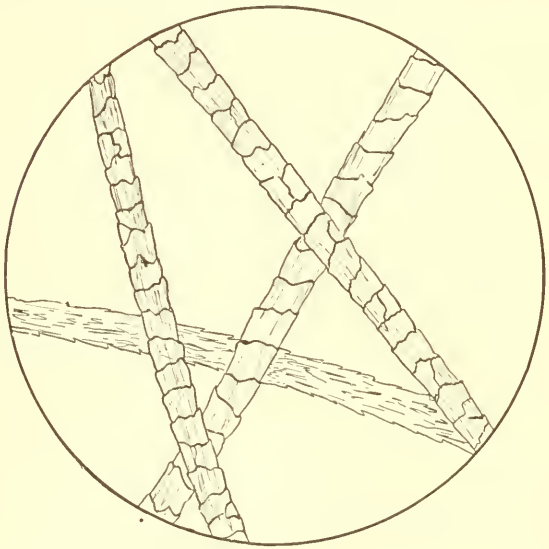


Fig. 97.—Wool-hairs of Cashmere. (×350.)
(Micrograph by author.)

[1] The supply of true cashmere is relatively small as the goat is not bred in great numbers and each goat yields but a small weight of fiber. According to Barker, the best cashmere is recovered as noil in the combing operation; the length of the fiber is from 2 to 3 ins., and the qualities are classified as "first" and "seconds," brown or white. The fiber is very light and fluffy and therefore needs much care in spinning. It is used for shawls, dress fabrics and hosiery requiring a soft handle and light weight.

At the point of the fiber the epidermal scales are either entirely absent or are so thin as to be scarcely visible. The fiber is very cylindrical; the scales have their free edge finely serrated, and the edge of the fiber also presents the same appearance (Fig. 97).

The following table by E. W. Tetley (*Textile Manufacturer*) gives a comparison between cashmere and some of the other similar fibers:

	Diameter.				Quality in Wool Top Terms.
	Greatest.	Least.	Average.		
Cashmere	0.0020	0.0004	0.0006	1/1666	90's
Vicuña	0.0006	0.00027	0.00047	1/2128	Over 100's
Goat hair (E. Indian)	0.0040	0.0009	0.0030	1/333	26's
Human hair (Chinese)	.....	.....	0.0030	1/333	26's

6. Goat-hair.—Besides mohair and cashmere, the hair of the common goat is also used at times. In trade there are four varieties of hair derived from the goat: ordinary goat-hair, meadow goat-hair, angora wool (mohair), and Thibet wool (cashmere). Goat-hair has the following microscopical characteristics (Höhnel): It is white, yellow, brown, or black in color, and generally from 4 to 10 cm. long. It consists largely of beard-hairs, which, like pulled wool, nearly always show the hair-root. The average hair exhibits the following structure (Fig. 98): At the base it is about 80 to 90 microns thick; the root is about $\frac{1}{3}$ mm. long; the marrow is just visible at the root, then rapidly increases in thickness, so that a few

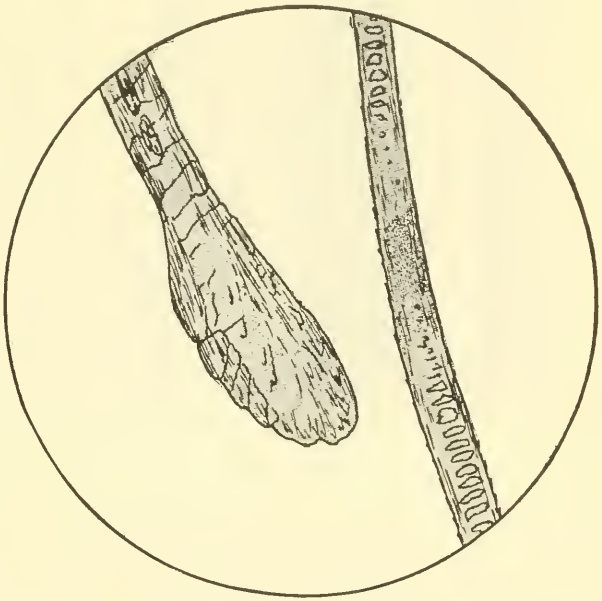
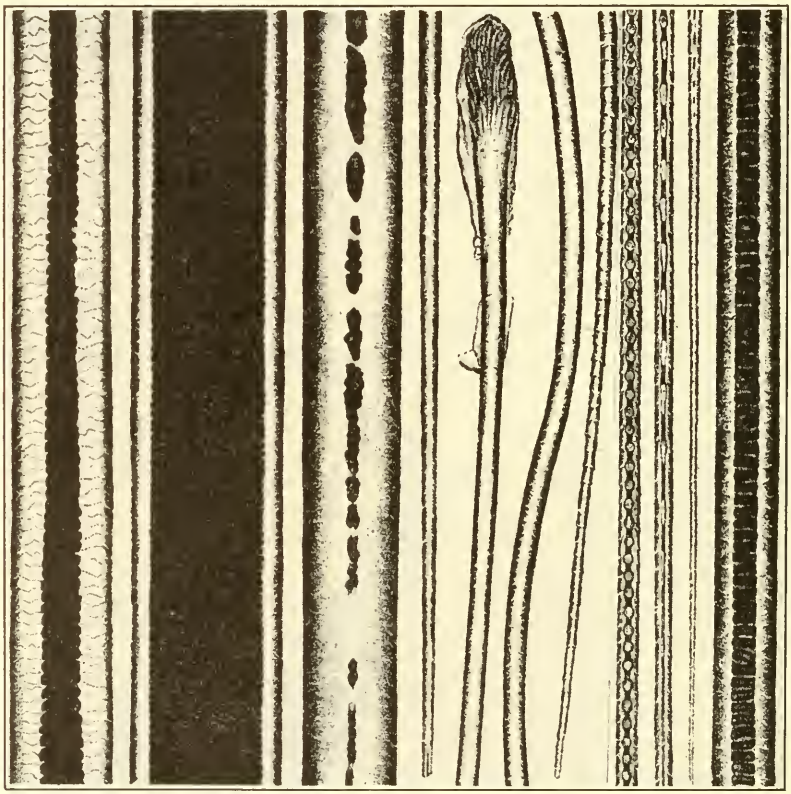


FIG. 98.—Hair of Common Goat. (×350.) Showing hair-root and medullated fiber. (Micrograph by author.)

millimeters from the base it is 50 microns thick, where the thickness of the hair amounts to from 80 to 90 microns. The cortical layer from this point on forms a very thin cylinder. The cross-section is round; the epidermis consists of broad scales about 15 microns long, the forward edges of which are scarcely thickened, but appear as if terminating in a sharp line; furthermore they are not serrated. The medullary cells are thick-walled, narrow, and flattened. Toward the end the hair is very



B *A*

Fig. 99.—Fibers of Goat. *A*, Fine wool-hairs; *B*, coarse beard-hairs. (Löbner.)

brittle and easily broken. Other authors note the presence of very narrow air-clefts between the medullary cells as being quite characteristic of goat-hair. Colored goat-hair shows the presence of pigment matter in all of its tissues; in such fibers the marrow appears black (Fig. 99).

The hair obtained from the meadow goat, according to Höhnel, consists of wool-hairs about 30 cm. long. At the base it is 100 microns thick, free from marrow; the epidermal scales here are very narrow, thin, and finely serrated, overlap each other in thick layers, and have no thickened edges

Around the total circumference there are 4 to 5 scales, whose free part is about 10 microns long and 40 to 50 microns broad. The fibers exhibit a regular and coarsely striated appearance. In the center of the cross-section the fiber appears spongy, exhibiting a trace of a kind of marrow. Further up the fiber acquires a thickness of about 90 to 95 microms and finally 120 microns, without, however, changing its structure. About 10 to 15 cm. from the base, the marrow cells make their first appearance as spindle-shaped cells, which often are seen only in broad fibers. These cells gradually become elongated and round, and finally occur continuously as a marrow cylinder. The cells themselves become less broad, and are arranged in several series, and finally form a large cylinder which is surrounded by a very narrow cortical layer and a scarcely visible epidermis. The marrow usually continues up to the broken-off point of the hair. The greatest breadth amounts to 150 microns, 10 microns on each side of which is the cortical layer. The fiber as a whole is very uniformly round.

Hanausek [1] calls attention to the fact that certain kinds of sheep's wool closely resemble goat's wool, having numerous beard-hairs present showing a broad medulla. Under the microscope goat-hairs in their middle part are characterised by broad, short, parallel medullary cells. Air (together with dried granular contents) is generally present in the medullary cells of white hairs, giving the medulla the appearance of a broad, black band. In the beard-hairs of coarse sheep's wool the appearance is much the same (Fig. 100, *A* and *B*). If, however, the fibers are mounted in potash and gently warmed, they swell greatly and the medullary cells stand out sharply and distinctly. In wool these appear as large round cells, while in goat's hair they remain elongated and the original parallel arrangement is not altered (see Fig. 101, *A* and *B*). According to Hanausek this difference is sufficiently characteristic to permit of the distinction between sheep's wool and goat's wool at a glance.

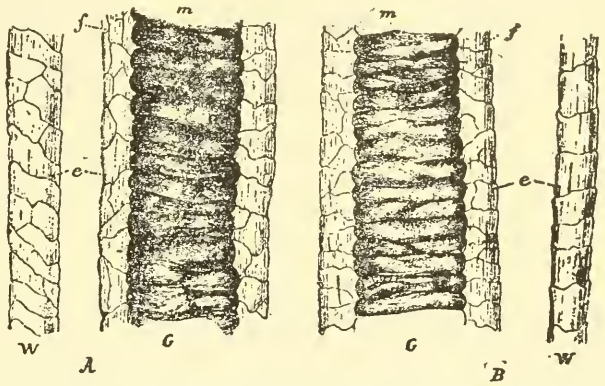


FIG. 100.—*A*, sheep's wool; *B*, goat's wool; *W*, wool-hair; *G*, beard-hair; *e*, epidermis; *f*, fiber layer; *m*, medulla. (After Hanausek.)

[1] *Microscopy of Technical Products*, p. 134.

7. Alpaca and its varieties *vicuña* and *llama* are the wools of the domesticated goat of Peru. The animal is a native of the mountainous slopes of the Andes, and if left alone grows hair to nearly a yard in length, though the usual clip has a staple about 9 to 10 ins. long, when they are stronger and more uniform. In the fine qualities the staples are well formed, and in this respect resemble those of a fine English luster or a Cape kid mohair; but in the coarser qualities they are somewhat disorganised.

Alpaca wools have the disadvantage of being mostly colored from brown to black. Though largely used in South America for the production of various fabrics, they do not find much application in the

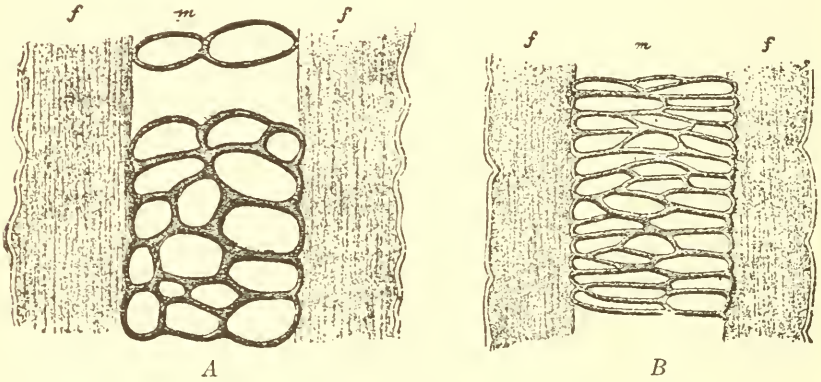


FIG. 101.—*A*, Beard-hair of sheep, and *B*, of goat after warming in potash; *f*, fiber cells, becoming disintegrated; *m*, medullary cells, swollen and no longer showing granular contents. (After Hanausek.)

general textile industry. In Bolivia there are about 200,000 alpacas. The animal belongs to the same family as the llama and vicuña, but its legs are shorter than those of the llama. There are also a large numbers of alpacas in Peru.[1] The alpaca is sheared about every two years and yields about 10 lbs. to the fleece. The alpaca skins are also used for rugs.

[1] These animals are little known to commerce, and are really but little known outside of the Andean uplands of South America. The camels of the Old World and the llama and allied species of the New World, all belong to the same family, and while the genus *Oris* is to be found over the four quarters of the world, the llama and its kind demand conditions of environment which markedly restrict their distribution. Even along the extensive ranges of the Andes, the llama and alpaca are not found north of the Equator, because throughout the entire length of the northern Cordillera the natural food of the animals, *ichu*, a coarse fine-pointed grass, is absent. The llama and alpaca have been domesticated from the earliest antiquity. In ancient days their flesh formed the main meat supply of the Inca, and the llama was employed as the chief means of transportation for merchandise, while its coarse hair supplied the

There is another product in trade which goes by the name of vicuña (French *vicogne*) which must not be confused with the true South American fiber, it being simply a trade name for a mixture of cotton and wool. " Gorilla " yarn is a complex mixture of such hair fibers as alpaca, sheep's wool, and mohair, with cotton and silk waste. It is rugged and knotty in appearance, and is chiefly used for the manufacture of ladies' dress material. The name alpaca is also given to a variety of wool substitute.

The South American wools often give rise to wool-sorter's disease in those handling them. This disease is anthrax and is caused by the presence of a certain microbe in the fiber. All alpaca, cashmere, Persian and camel-hair fleeces should be opened over a fan with a down draught. Van mohair or Turkish mohair should be washed and sorted while damp. Persian wool should be disinfected before sorting. Wool-sorter's disease is caused by *Bacillus anthracis*, which may enter the system either by the skin (through the medium of an abrasion or cut) or by the internal organs, being introduced with the food. In the former case it gives rise to pustules, which become painful and cause excessive perspiration, fever, delirium, and sundry disorders. In the latter case it gives rise to the most serious results, leading to blood-poisoning and inflammation of the lungs, which often prove speedily fatal.[1]

True alpaca is obtained from the cultivated South American goat *Auchenia paco.* It occurs in all varieties of colors, from white, through brown, to black. The reddish brown and not the white variety, however, is the most valuable. Like other goat-hairs, alpaca consists of two varieties of fibers, a soft wool-hair and a stiff beard-hair. The wool-hairs of the reddish brown variety are from 10 to 20 cm. in length[2] and from

lower classes with the raw materials from which were woven their apparel and blankets. Attempts have been made to introduce the llama into Australia, but without success. The alpaca also fails to thrive when removed from its high altitudes, which range about 13,000 ft. above the sea. Higher still, the guanaco and vicuña, the wild members of the species, are found.

[1] South American wools and fibers that are infected with anthrax frequently have to be properly sterilised before manufacturing. Treatment with formaldehyde vapors is often employed. The Dinsley-Pulman system of sterilising anthrax-infected wools uses an apparatus which, by a combination of X-rays and ultra-violet rays, will sterilise anthrax germs as effectually as the formaldehyde system, but will do it in the bale and so save time, labor and expense in unpacking, washing, scouring and re-packing the bale.

[2] According to Barker, the ordinary alpaca clip yields a length of about 9 ins., but much is allowed to grow for two, or even three years, when it reaches a length of about 30 ins. This great length, however, is liable to cause weakness in the fiber resulting in much waste in manufacture. Alpaca wool is usually classified as "low," "medium," and "fine." In England the fiber is generally known as "Arequipa fleece," Arequipa being the Peruvian port from which it is shipped. Alpaca is mostly used for dress goods, linings and overcoat facings.

11 to 35 microns in diameter (Fig. 102). The fiber is very smooth, the serrations on the edge being faint and indistinct, and the scales are almost imperceptible and, in many cases, apparently absent altogether; the diameter is also very uniform, and there are coarse brown longitudinal striations but no medulla, though isolated medullary cells are at times observed. The wool-hairs of the white variety are very distinctly serrated on the edge, and the fiber is not so uniformly thick. The beard-hairs of the brown variety are comparatively few in number, are from 5 to 6 mm. in length and about 60 microns in diameter, and the latter is very uniform. A very broad continuous medullary cylinder is present, 45 to 50 microns wide; the medullary cells are very indistinct, but are filled with coarse granules of matter. The cortical layer shows occasional fissures, and the brown coloring matter is principally distributed through the external cortical layer, though very irregularly. The beard-hairs of the white variety also occur rather sparingly; they are from 20 to 30 cm. in length, and 35 microns in thickness at the lower end and about 55 microns towards the upper end. The medulla is broad and continuous, and nearly always filled with a coarsely granulated matter of a gray color (Fig. 103). The medulla consists of a single row of short cylindrical cells, but, as the walls are very thin, the cells are to be seen only with difficulty. The cortical layer is coarsely striated and frequently shows fibrous fissures; the edge of the fiber is not sharply serrated.

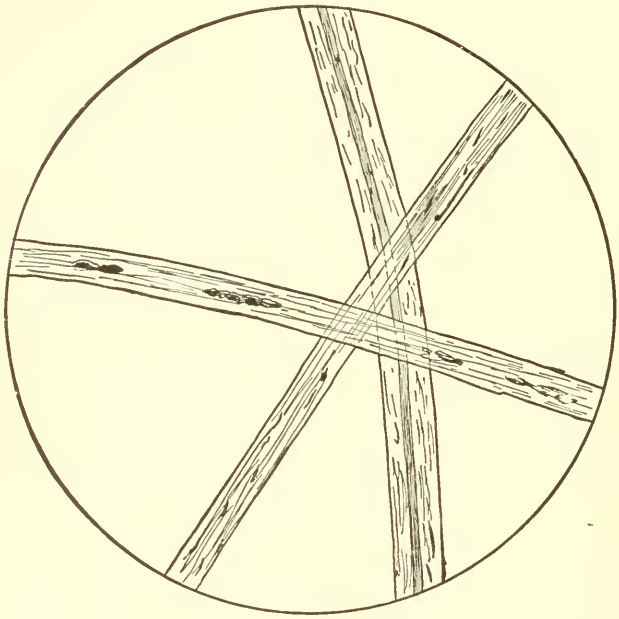


Fig. 102.—Alpaca Fibers. (×350.) (Micrograph by author.)

The fibers of alpaca are coarser than either vicuña or camel-hair, and the thick medullated fibers are present in much greater proportion than the fine woolly fibers. The distribution of the pigment matter is more uniform in alpaca fibers than in those of vicuña or camel-hair.

The alpaca is smaller than the llama and weighs on the average about 180 lbs. The neck is shorter and is well covered with hair which forms in the region of the throat a distinct beard-like fringe. A cross-breed between the alpaca and the llama has resulted in the production of hair of good length, luster and fineness. The " suri " type of alpaca, an animal with a distinct curl along the entire length of the fiber, is much sought after, as this fiber is in good demand by manufacturers for the production of a special artistically finished cloth. This "suri" type is the outcome of mere chance breeding. The hair of the alpaca is of remarkable fineness and luster, and there is a variety of colors ranging from white through blue, gray, fawn and orange to dark brown. These colors show a great fastness to light and to milling and finishing operations, and are being much used in the hosiery trade for natural colored alpaca yarns. There is no doubt that a much wider market could be opened were there a larger supply of this very attractive fiber.

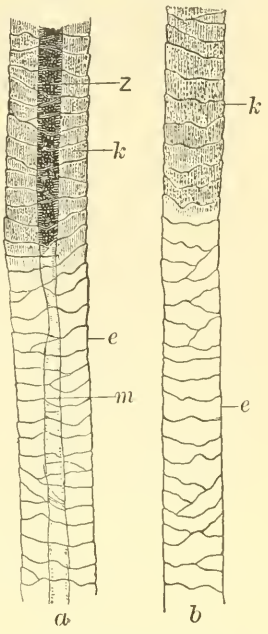


FIG. 103.—Fibers of Alpaca. (Höhnel.) (×350.)

a, Beard-hair containing medulla; *b*, wool-hair free from medulla; *e*, cusp-like scales, thin and broad; *k*, granulated streaks on the fibrous layer; *m*, medullary cylinders; *z*, small medullary cells.

8. Vicuña Wool is another South American product obtained from *Auchenia viccunia*, the smallest of this general class of goat-like camels. It is not a cultivated animal, and is evidently disappearing, hence the fiber is not met with in trade to any great extent at the present time.

The vicuña is antelope-like in shape, and in appearance, color and movement resembles the gazelle of East Africa. It weighs from 75 to 100 lbs. The head is proportionately too large for the size and delicacy of the neck, which is long and curving. The fleece is light reddish-brown in color, shading off to a light fawn down the legs and along the under surface of the body. On the breast is long, coarse, white hair which gives the animal a very characteristic appearance. The hair of the vicuña is very valuable; it is more esteemed than the down of the Canadian beaver or the fleece of the Syrian goat. During recent years some vicuña animals have been domesticated and used for cross-breeding purposes with the alpaca, resulting in the production of a hair which for softness of handle and fineness of fiber will be difficult to equal. Steps are now being taken to farm these valuable hair-bearing animals along approved scientific lines and stringent laws have been enacted in Peru to protect the vicuña

from destruction. By the process of selection, judicious breeding and proper farming and cross-breeding, it should be possible to produce a hair of very great intrinsic value, of exceptional softness in handle, and of good length and luster. The cross between the alpaca and vicuña is known as the "paco-vicuña."

Vicuña is a soft, delicate fiber, usually of a reddish brown color, and much resembles alpaca, though it is usually finer that either alpaca or camel-hair, and is characterised by a very soft, almost greasy, touch. It also shows the presence of a fine wool-hair and a coarse beard-hair; the former is from 10 to 20 microns in diameter, while the latter is 75 microns wide. The scales of the wool-hair are very regular and rather easy to distinguish, but generally no medulla is to be seen. The cortical layer is finely striated and frequently contains fibrous fissures (Fig. 104). The beard-hairs, however, show a well-developed medulla, mostly dark in color. The fibers of the wool-hair are very uniform in diameter and about 20 cms. in length. Mitchell and Prideaux[1] call attention to the fact that the disposal of the pigment is an important characteristic of the vicuña fiber. In the small fibers it is regularly distributed in uniform, faintly defined dashes. In the large medullated fibers, however, the distribution of the pigment may take a different form; in addition to the streaks and lines found in the smaller fibers, there may occasionally be noted circular patches of pigment.

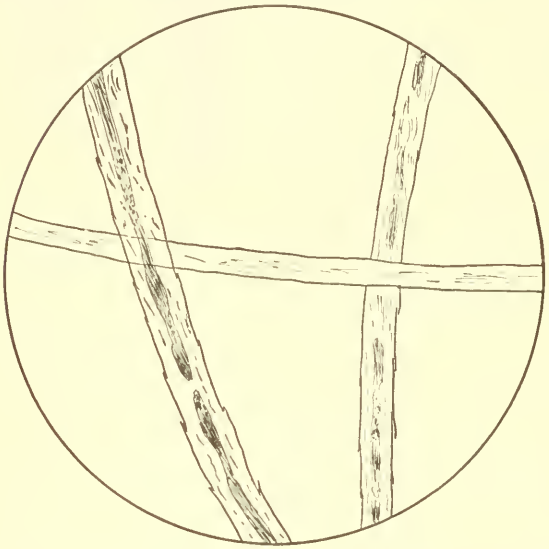


Fig. 104.—Vicuña Fibers. (×350.) (Micrograph by author.)

An artificial wool substitute also goes by the name of vicuña or vicogne yarn, but bears no resemblance to the true South American fiber. It consists principally of a mixture of cotton with sheep's wool, but is frequently mixed more or less with wools and coarse beard-hairs of poor spinning qualities obtained from various goats (of Asia Minor), from camels, and from South American wools. It is of poor quality and generally yellowish

[1] *Fibers Used in Textile Industries*, p. 34.

brown in color. It is only used for felted materials or for very coarse fabrics.

The table on page 226 given by E. W. Tetley (*Textile Manufacturer*), compares the different physical properties of the fibers of mohair, alpaca and camel's hair.

9. Llama Fiber.—This fiber is obtained from a goatlike animal (Fig. 105) indigenous to several South American countries, principally Peru and Bolivia. The latter country contains about 500,000 llamas and they constitute the traditional pack animal of the country. They are sheared at intervals of two to five years, though often the shearing does not take place until the animal dies. When sheared each two years the llama gives about 5 lbs. of wool. The fiber is quite coarse and always very dirty. Most of the wool is used by the natives in their weaving and very little of it comes into general trade.

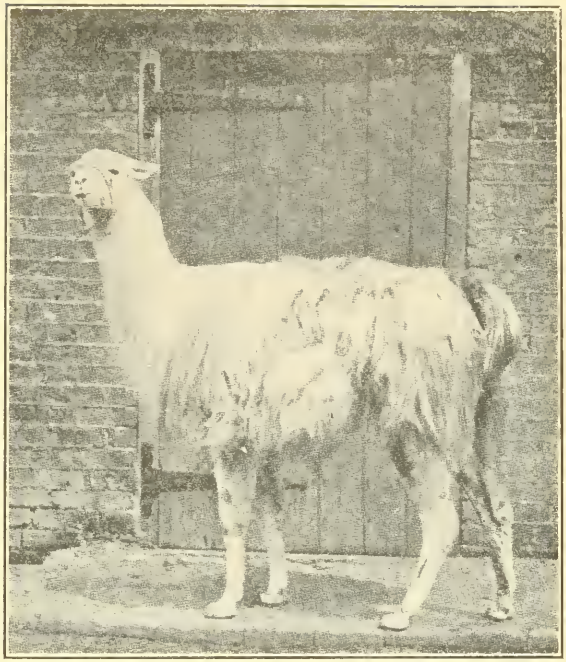


FIG. 105.—Llama.

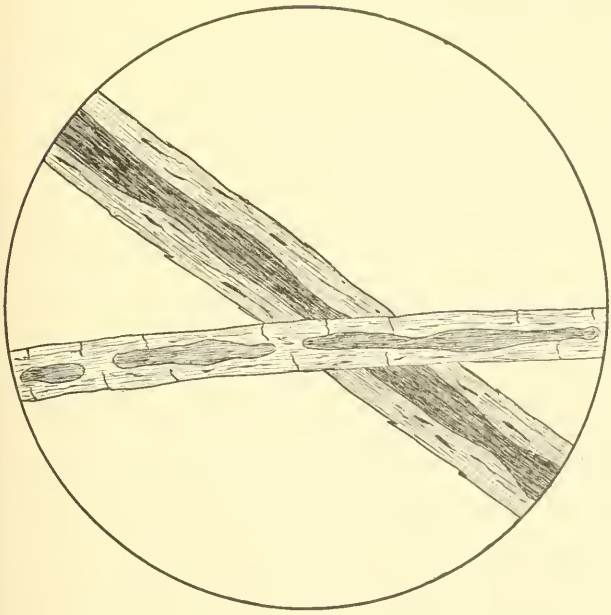


FIG. 106.—Llama Fibers. (×350.) (Micrograph by author.)

The fiber of llama exhibits scarcely

Material.	Color.	Luster.	Handle.	Strength.	Waviness.	Length in Inches.			Diameter in Inches.				Quality in Wool Top Terms.	Approx. Counts of Yarn, Limit.	Uses.
						Longest.	Shortest.	Bulk.	Greatest.	Least.	Average.				
Mohair:															
Coarse...	White	Extremely lustrous	Fairly soft	Very strong	Straight	11	8	9½	0.0026	0.0009	0.0017	1/588	36's		
Medium..	White	Extremely lustrous	Soft	Very strong	Slightly wavy	9	7	8	0.0020	0.0090	0.0013	1/769	46's	36's	Luster dress goods, linings, plushes, upholsteries, braiding, etc.
Fine.....	Pure white	Very lustrous	Very soft	Very strong	Slightly wavy	8	5½	6½	0.0013	0.0005	0.0009	1/1111	60's		
Alpaca:															
Coarse...	Self-color or mixture	Very lustrous	Soft	Very strong	Rather wavy	11	7	8½	0.0024	0.0009	0.0014	1/714	40's		
Medium..	Self-color or mixture	Lustrous	Very soft	Strong	Rather wavy	9	5½	7½	0.0018	0.0007	0.0011	1/909	56's	44's	Fine luster dress goods, linings, etc.
Fine.....	Self-color or mixture	Lustrous	Extra soft	Strong	Rather wavy	8	4½	6	0.0013	0.0005	0.0008	1/1250	64's		
Camel-hair:															
Coarse...	Brown	Fair luster	Fairly soft	Very strong	Rather curly	6 to 9	3½	5	0.0031	0.0005	0.0012	1/833	56's		
Medium..	Brown	Rather lustrous	Soft	Strong	Rather curly	6	3	4	—	—	0.0009	1/1111	60's	40's	Beltings, carpet yarns, dress goods, etc., shawls, hosiery
Fine.....	Brown	Slightly lustrous	Extra soft	Fairly strong	Rather curly	4	2½	3	0.0011	0.0004	0.0007	1/1429	70's		

any visible surface scales, but has well-developed isolated medullary cells. It also consists of two classes of fibers, both of which show longitudinal striations (Fig. 106). The wool-hair is from 20 to 35 microns in diameter, while the beard-hair averages 150 microns. The llama wool comes from the *Auchenia llama*, a cultivated animal.

The llama is the largest of the Andean camels. Its average weight is about 250 lbs., and it has a life of ten to fourteen years. Its fleece is thick and coarse; the neck, which is long, is well covered, but the throat is devoid of long hair. The fleece terminates abruptly along the bottom line of the trunk, and has a staple of 10 to 12 ins. in length. It is principally used in the making of sacks and coarse blankets.

The wool from another variety, *Auchenia huanaco*, is used to some extent in South America, though it seldom appears as such in general trade. This latter animal is not cultivated, but is hunted wild, and is gradually disappearing. Huanaco and llama are nearly always mixed more or less with alpaca and brought into trade under the latter name.

Huanaco or guanaco, like the vicuña, is not domesticated. It is somewhat larger than the vicuña, and its fleece is russet-brown in color with an overmantle of long, coarse hair of slightly darker hue. The guanaco has never been domesticated, nor has it ever been used for cross-breeding purposes.

There is but little difference to be found among these three fibers, owing to the close relationship of the animals from which they are derived, and more especially as different portions of the fleece from all varieties of *Auchenia* give wools of entirely different quality, with respect to color, fineness of staple, and purity from coarse stiff hairs; and the corresponding portions from the different animals are usually graded together.

10. Camel-hair is used to quite an extent in clothing material, and is characterised by great strength and softness. It has considerable color in the natural state, which does not appear capable of being destroyed by bleaching; hence camel-hair is either used in its natural condition or is dyed in dark colors. There are two distinct growths of fiber on the camel: the wool-hair, which is a fine soft fiber, largely employed for making Jäger cloth, and the beard-hair, which is much coarser and stiffer, and is mostly used for carpets, blankets, etc.[1] Both fibers show faint markings of scales on the surface and well-developed longitudinal striations. The

[1] Barker states that true camel-hair is a fine, downy material, about 5 ins. long, of a yellowish or brownish color. Long, strong fibers are invariably found in this, coming from the underparts of the camel, and these must be combed out. There are many types of camel-hair, such as Chinese, Persian and Russian, but all are classified as firsts, seconds and thirds, the first being freer from coarse fibers and more uniform. True camel-hair is not very strong, and thus needs careful treatment in manufacture to avoid excessive waste. The fine fiber is employed for dress goods and linings, while the coarse fiber, which is exceptionally strong, is used for beltings and the like.

beard-hair always exhibits the presence of a well-defined medulla, which is large and continuous, while the wool-hair either shows only isolated medullary cells or none at all. The diameter of the wool-hair is from 14 to 28 microns, while the beard-hair averages 75 microns (Fig. 107). The wool-hairs are about 5 to 6 cm. in length, are rather regularly waved, and are usually yellow to brown in color; while the others are about 10 cm. long and are dark brown to black in color. The epidermal scales of the latter are quite rough, which give the edge of the fiber a saw-toothed appearance. The presence of large spots, or motes, of brown coloring matter, especially in the medulla, is quite characteristic. These are usually granular in form. The

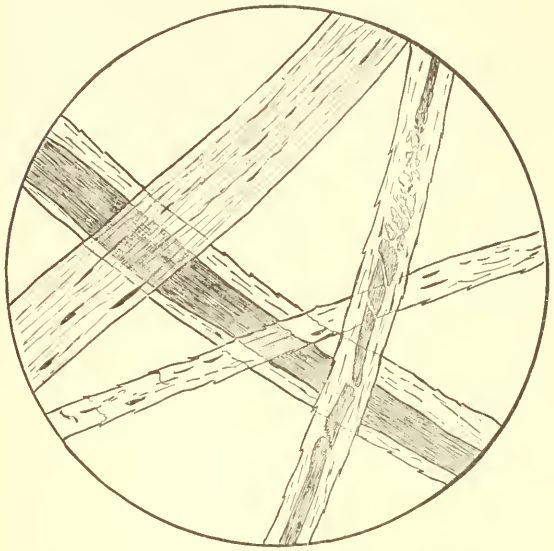


Fig. 107.—Camel-hair. (×350.) (Micrograph by author.)

Fig. 108.—Hair Fibers. (1) Fine alpaca; (2) coarse alpaca; (3) Russian camel-hair; (4) Chinese camel-hair; (5) Thibet cashmere; (6) East Indian goat-hair. (Tetley.)

beard-hairs of the camel are to be distinguished from corresponding cow-hairs by smaller diameter, thicker epidermis, and narrower medullary

cells with thicker walls, which are generally darker in color than the enclosed pigment matter. Camel-hair is to be distinguished from cow-hair by the thick-walled medullary cells and the streaks of coloring matter.

According to Mitchell and Prideaux the fibers of camel-hair are generally coarser than those of vicuña, a greater proportion of the larger medullated fibers being present. The scales of the finer fibers are also less conspicuous than those of vicuña, hence the latter has a softer touch. The distribution of the pigment cells in camel-hair is very irregular; some of the finest fibers appear to have none, while in others flecks and dashes of pigment may be seen in the otherwise clear transparent hair.

Prideaux [1] gives the following summary of differences between vicuña, camel-hair, and alpaca:

Vicuña.	Camel-hair.	Alpaca.
The finest fibers of the three; few coarse medullated examples; scales least conspicious	Intermediate in fineness; medullated fibers common; scales most conspicuous	The coarsest fibers, few non-medullated
Largest difference in size between non- and medullated fibers	.....	Least difference between non- and medullated fibers
Pigment always present, except in a few of the large opaque medullated fibers	Many of the smaller fibers colorless	Many fibers, especially the larger ones, colorless
Amount of pigment very uniform; disposal rather regular; circular nuclei rare, and only in medulated fibers	Amount of pigment variable; disposal highly irregular, circular nuclei frequently seen in fibers of all sizes. Distinctive streaks and blurs well marked	Amount of pigment very variable; disposal very regularly diffused, in pale specimens almost as if dyed; circular nuclei never seen

Notwithstanding these characteristic differences, it is a very difficult matter to differentiate definitely between these three forms of hair fibers, and an opinion as to which fiber is under consideration must usually be referred to other considerations than a microscopic test.

Camel-hair noils are the short fibers obtained from the combing of camel-hair. They also consist of two kinds of fiber: (*a*) very fine, curly, reddish or yellowish brown hairs, about 4 ins. in length, and known in trade as camel-wool; and (*b*) coarse, straight, dark to blackish brown body hairs, about 2 to $2\frac{1}{2}$ ins. in length.

[1] *Jour. Soc. Chem. Ind.*, 1900, p. 8.

11. Cow-hair is extensively employed as a low-grade fiber for the manufacture of coarse carpet yarns, blankets, and a variety of cheap felted goods. It is seldom used alone, however, on account of its short staple. It comes principally from Siberia. The diameter of cow-hair varies from 84 to 179 microns and the length from $1\frac{1}{2}$ to 5 cm. The fibers occur in a variety of colors, including white, red, brown, and black. In its microscopic appearance the surface of the fiber is rather lusterless; the ends are very irregular, being blunt and divided. The medullary canal is well marked, occupying about one-half the diameter at the base and tapering towards the free end, where it occupies only one-fourth the diameter. Isolated medullary cells are also of frequent occurrence (Fig. 109). Cow-hair (including also calf-hair) nearly always shows the hair-root, as the fibers are removed from the hide by liming and pulling. Cow-hair may be distinguished from goat-hair by the number of epidermal scales, by the folds in the medullary canal, and by the single row of cells in the medulla. The medulla does not extend to the apex, which is also usually devoid of epidermis.

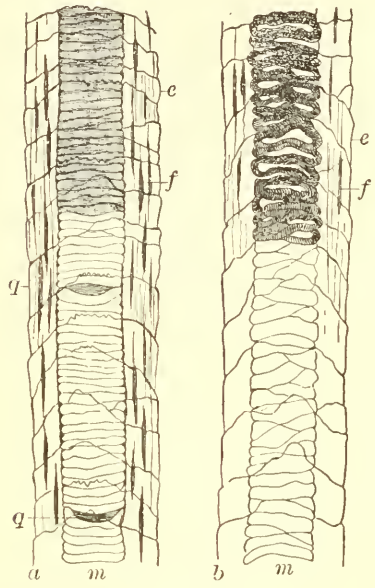


FIG. 109.—*a*, Cow-hair; *b*, goat-hair. (Höhnel.) (×300.) *q*, characteristic fissures in marrow; *m*, marrow or medulla filled with air; *f*, fibrous fissures; *e*, tile-shaped scales.

Cow-hair shows the presence of three kinds of fibers:

1. Thick stiff beard-hairs from 5 to 10 cm. in length, and retaining a long narrow hair follicle; above this is the neck of the hair, containing a medullary cylinder consisting of a single series of cells as well as isolated medullary cells. At this part of the fiber the epidermal scales are very thin and broad, and the forward edges present a serrated appearance; the neck of the hair is about 120 microns in thickness. Above this the hair rapidly increases to about 130 microns in thickness, and the medullary cylinder becomes broad (75 microns) and consists of narrow brick-shaped elements, arranged one on top of the other. The cortical layer is finely striated, the epidermis is indistinct, and the edge of the fiber is smooth. The medullary cells are very thin-walled and contain a considerable amount of finely granulated matter. Toward the pointed end the fiber becomes colorless, and shows distinct fibrous fissures; the medullary cylinder disappears, but the epidermis is not altered. The chief difference between these hairs and the beard-hairs of the goat is that in the former the medullary cells consist of only a single series, and are very thin-walled, and are also frequently isolated from one another, while they are filled with finely granulated matter.

2. Soft, fine, beard-hairs possessing the same general structure as the foregoing, but not so thick, the neck of the hair being 75 microns in diameter and not possessing any medulla. Above this the medullary cylinder consists of very thin-walled cells arranged in isolated groups; the epidermal scales overlap one another and are almost cylindrical, are narrow, and with finely serrated edges. About 1 cm. from the base the medullary cylinder becomes discontinuous and breaks up into isolated medullary cells, which continue until the middle of the fiber is reached, where they disappear completely; toward the pointed end of the fiber they reappear and again become a continuous cylinder, consisting of only a single series of cells, however. These are well filled with a dark medullary substance.

3. Very fine soft wool-hairs, free from medulla, and at most only 1 to 4 cm. in length, and frequently only 20 microns in thickness. The epidermal scales are rough, causing the edge of the fiber to be uneven and have a serrated appearance. The hairs also show frequent longitudinal fibrous fissures.

Calf-hair has the same general structure and appearance, though there is a greater amount of soft wool-hairs present.

As cow-hair is at times to be met with in admixture with wool as an adulterant of the latter, the following method of distinguishing between the two, devised by Hanausek, is of interest. The microchemical reaction of cow-hair with a warm solution of potash is very similar to that of goat-hair since in both fibers the medullary cells are transversely elongated and arranged parallel to one another. An important distinction from goat-hair, however, is the presence of transverse air-spaces. Figure 110 shows the comparison between sheep's wool and cow-hair.

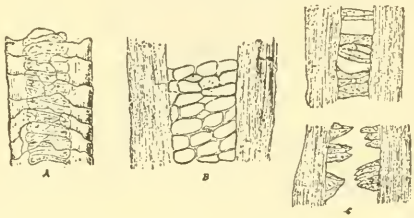


FIG. 110.—*A*, Hair of Leicester wool in water; *B*, same after warming in potash; *C*, cow-hair after warming in potash. (After Hanausek.)

12. Minor Hair Fibers.—(*a*) **Horse-hair** has a diameter of 80 to 100 microns and a length of 1 to 2 cm. (Fig. 111). Like cow-hair, it also occurs in a variety of different colors. Horse-hair is more lustrous than the foregoing, however, and though when viewed under the microscope the ends of the fibers are irregular and often forked, they taper off to points. The medullary cylinder is rather large, occupying about two-thirds of the diameter at the base of the fiber and tapering to about one-fourth of the diameter at the free end. The medulla consists of one to two rows of very narrow leaf-shaped cells. Isolated medullary cells are of frequent occurrence, especially at the point. The cortical layer frequently contains numerous short orifices or fissures. These remarks refer to the body-hairs of the horse; the hairs of the tail and mane are much longer, reaching from several inches to a foot or more. They find but little use in ordinary

textiles, but are much used as stuffing materials in the manufacture of upholstery.

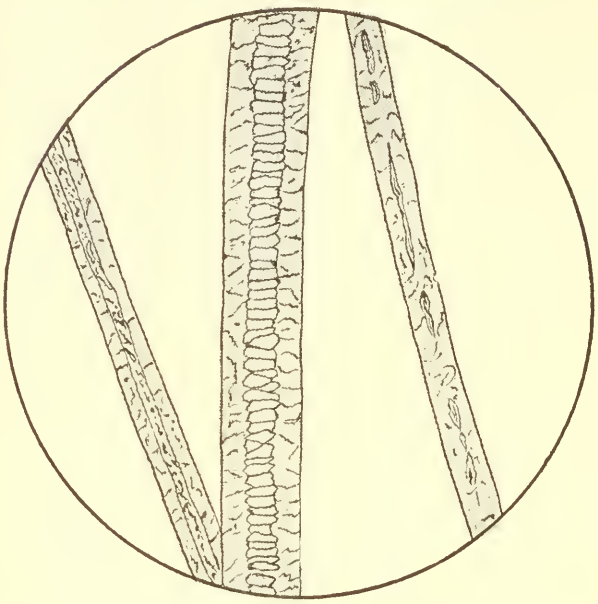


Fig. 111.—Horse-hair. (×100.) (Micrograph by author.)

(*b*) **Cat-hair** varies in diameter from 14 to 34 microns and in length from 1 to 2 cm. The fibers occur in a variety of colors and have a good luster. The ends are quite regular and very pointed. The medullary canal contains a single series of regular cells occupying one-half to three-fifths of the diameter of the fiber. The cortical layer is well developed, and its inner face is grooved so as to fit over the medullary cells. There is a thin irregular epidermis which envelops the fiber (Fig. 112).

(*c*) **Rabbit-hair** fibers are usually light brown in color and measure from 34 to 120 microns in diameter, and from 1 to 2 cm. in length. The medullary canal is filled with several series of cells, quadrangular in shape and with thin walls. They are also arranged in a very regular manner. By careful observation

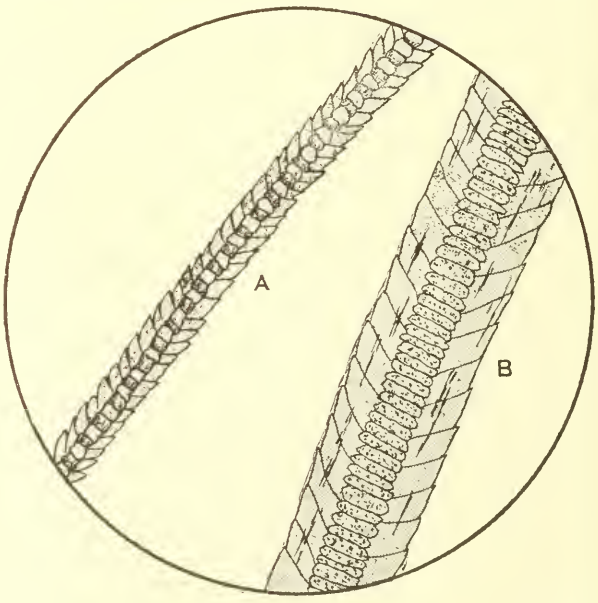


Fig. 112.—Hairs of Cat. (×350.) *A*, Fine-wool hair; *B*, coarse beard-hair. (Micrograph by author.)

spiral striations may be noticed on the finer fibers. The epidermal scales are very thick and their forward edges terminate in a sharp point (Fig. 113). Each scale is placed cornucopia-like into the next lower one, and is drawn out into 1 to 3 large waves. At the base of the fiber the medulla consists of a single row of cells, above the middle this increases to 2 to 4 rows, and further along the fiber the number of rows of cells increases up to 8, when the hair becomes very wide (Fig. 114). Like most pelt-hairs, the fibers are somewhat flattened at the base, and quite so at their broadest part. The cortical layer is only apparent towards the point where the medulla ceases. The fine wool-hairs of the

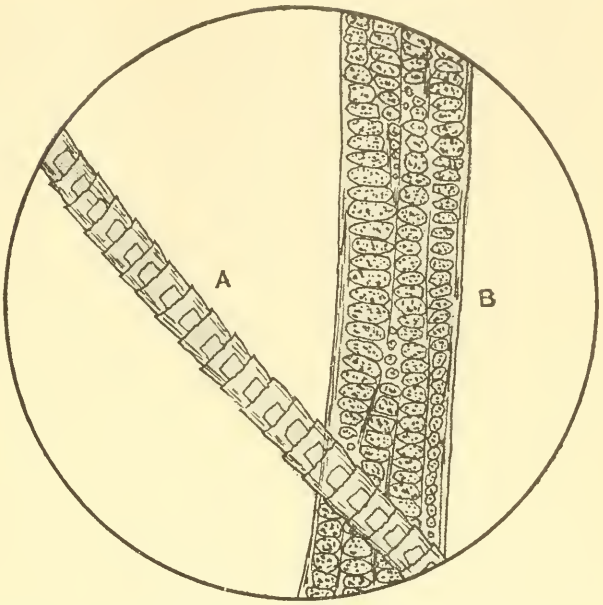


FIG. 113.—Rabbit-hair. (×350.) *A*, Wool-hair; *B*, beard-hair. (Micrograph by author.)

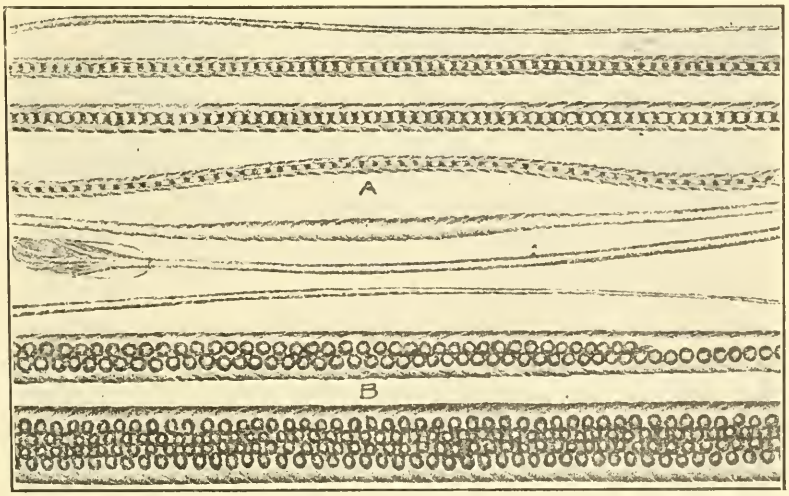


FIG. 114.—Fibers of Rabbit-hair. *A*, Fine fur fibers; *B*, coarse beard-hairs.

rabbit are much thinner than the above, the greatest thickness being about 20 microns. Otherwise they correspond in structure to that part of the above fiber near the base.

(*d*) **Deer-hair.**—This has a very characteristic structure. It is 2 to 4 cm. long, brittle, white at the lower end and brown at the thinner upper end. Most of the hairs still show the thin small root and the natural point. The root is relatively very small (on the prepared washed hairs 90 microns broad and 300 microns long). It passes into a neck about 250 microns long, which is only 60 microns thick and without any medulla. This neck portion consists of short fibers without granulation, containing numerous broad fissures, and of a very soft, scarcely visible epidermis, consisting of narrow, transversely broadened serrated elements. Then the hair suddenly becomes cone-shaped, thicker, and increases in diameter to 360 to 400 microns. The large medulla can no longer be seen without further preparation. The soft epidermis is scarcely visible; the total breadth of the fiber is filled up with large medullary cells, which besides appear very thick-walled and almost isodiametric (35 to 40 microns broad and 25 to 35 microns long). The cross-section through the fiber, however, shows that the cell-walls within the outermost zone are some 10 to 12 microns thicker, while all those lying farther inside are quite thin. The medullary cells are very large; all of them are apparently entirely empty or only filled with air; the cortical layer cannot be seen. Towards the point the hair again becomes thinner. At this point is to be found a brown pigment (beyond the limits of the medullary cells, and in median layer). Nearer the point the cell-walls themselves become brown and also contain a brown substance. The medullary continually becomes thinner, and consists finally of only one row of cells. At the very point the fiber consists only of the cortical layer and the epidermis.

Besides these thick hairs, there are also found thin, brown, short hairs, as well as intermediate forms. They have the same typical structure. The cortical layer in these does not appear so much diminished, and throughout the entire length of the fiber there is a brown pigment to be found, at least on the upper surface. At the end of the fiber the epidermal scales are thick, very short, and overlap one another very distinctly, being enclosed by one another in a tubular manner (Höhnel).

(*e*) **Boar Bristles.**—Under the microscope these appear striped, up to 500 microns thick. Their lower portion is free from medulla, or with a discontinuous medullary cylinder; the upper part has well-marked medulla, which in cross-section appears star-shaped, on account of which the bristles can be easily split at the ends. The epidermis is in several layers. It consists of 3 to 4, and more, layers of thin scales, which overlap one another, and the thin edges of which are corroded in a serrated manner. Hence from each of the broad epidermal scales only a narrow

edge projects, and the upper surface of the bristle appears covered with finely waved serrated cross-lines. The cortical layer is very prominent, and consists of very thick-walled elements, whose lumen appears full of cracks. In cross-section the lumen of the fiber appears like a short thick line. The medulla of the bristle consists of thin-walled parenchymous cells. Here and there appear isolated medullary cells enclosed in the

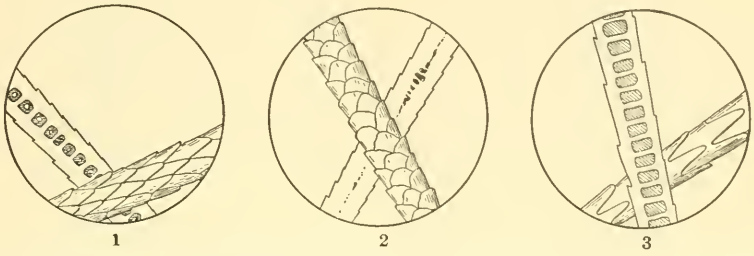


FIG. 115.—Fur Fibers. (1) Black bear ($d = 27\mu$); (2) cat ($d = 21\mu$); (3) ermine ($d = 17\mu$). (Hausman.)

fibrous mass. The bristles found in trade always show a root. They may be naturally colored white, yellow, red, brown, black, or gray, or they may be artificially dyed. The pigment is found in the form of fine granules, especially in the fibrous elements, and more frequently on the inside than on the outside (Höhnel).

13. Fur Fibers.—The term "fur" is usually applied to the pelts of various animals with the hair or wool-like covering still retained. It

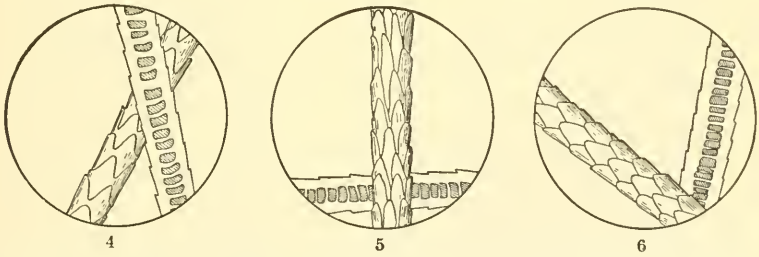


FIG. 116.—Fur Fibers. (4) Fitch ($d = 18\mu$); (5) red fox, Kolinsky ($d = 19\mu$); (6) Canada lynx, marten ($d = 19\mu$.) (Hausman.)

may also be used, however, for the hair by itself, removed from the skin, as for example when employed for the making of fur felt hats and the like. Though furs in the form of pelts can hardly be regarded in the sense of textile fibers in that they are not mechanically processed as textiles, nevertheless the methods of treating furs are such that they may be conveniently considered in this connection. These furs are treated for purposes of dyeing, bleaching, and finishing in much the same manner as

wools and hairs are treated in the making of textiles, consequently it will not be out of place to give them some consideration in the present volume.

At the present time furs are more or less "manufactured," that is to say, furs of one animal are treated in such a manner as to make them closely resemble those of another animal. The pelt of the muskrat, for

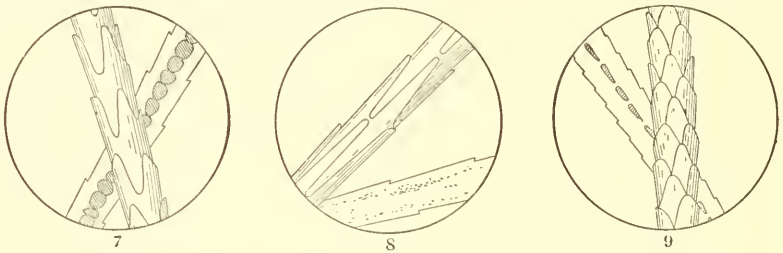


FIG. 117.—Fur Fibers. (7) Mink, American otter ($d = 18\mu$); (8) European otter, sea otter ($d = 10\mu$); (9) raccoon, Russian sable ($d = 20\mu$.)

example, is largely processed to make it resemble very closely the fur of the rarer and more expensive seal, giving a product known as "Hudson seal." The following table gives some of the better-known furs and their alteration products.[1]

ACTUAL FUR.	ALTERED TO RESEMBLE
American Sable	Russian Sable
Fitch, dyed	Sable
Goat, dyed	Bear
Hare, dyed	Sable or Fox
Kid	Lamb
Woodchuck (Marmot)	Mink, Sable, Skunk
Mink, dyed	Sable
Muskrat, dyed	Mink, Sable
Muskrat, pulled and dyed	Seal
Nutria, pulled and dyed	Seal
Nutria, pulled natural	Beaver, Otter
Opossum, sheared and dyed	Beaver
Otter, pulled and dyed	Sable
Rabbit, sheared and dyed	Seal, Muskrat
Rabbit, white	Ermine
Rabbit, white, dyed	Chinchilla
Kangaroo, dyed	Skunk, Marten
Hare, white	Fox
Goat, dyed	Leopard

One of the most important qualities to be considered in reference to a fur is its durability. Though this, of course, is dependent to a considerable degree on the methods employed in tanning the skin and in processing the

[1] Jones, *Fur Farming in Canada.*

fiber, it is also dependent to a great extent on the nature of the pelt itself. The following table gives the approximate relative durability of some of the common furs when employed for outside wear:[1]

Species.	Durability (Otter = 100).
1. Beaver	90
2. Bear, black or brown	94
3. Chinchilla	15
4. Ermine	25
5. Fox, natural	40
6. Fox, dyed	20–25
7. Goat	15
8. Hare	5
9. Kolinsky	25
10. Leopard	75
11. Lynx	25
12. Marten (skunk)	70
13. Mink, natural	70
14. Mink, dyed	35
15. Mole	7
16. Muskrat	45
17. Nutria (Coypu rat), plucked	25
18. Otter, sea	100
19. Otter, inland	100
20. Opossum	37
21. Rabbit	5
22. Raccoon, natural	65
23. Raccoon, dyed	50
24. Sable	60
25. Seal, hair	80
26. Seal, fur	80
27. Squirrel, gray	20–25
28. Wolf	50
29. Wolverene	100

In their physical and microscopical characters furs are very similar in general to wool and the other hair fibers which have already been considered. As a rule they are marked by the occurrence of considerable pigment matter in the medulla, and this may occur in four distinct types: (1) the discontinuous medulla, as in the duck-bill or platypus; (2) the continuous medulla, as in the red fox; (3) the interrupted medulla, as in the hair seal; and (4) the fragmental medulla, as in the otter. L. A. Hausman (*Scientific Monthly*) gives the following method for the microscopic examination of furs: Several hair shafts are taken and washed in a solution composed of equal parts of 95 percent alcohol and ether to remove any oily matter from their surface. They are then transferred to a clean glass slide, covered with a cover glass, and allowed to stand in a current of warm

[1] Peterson, *The Fur Trade and Fur Bearing Animals.*

air until thoroughly dry. Examination can now be made directly for those hairs whose structural elements are large and prominent, such as the otter and beaver. In other cases the hairs must be washed in the

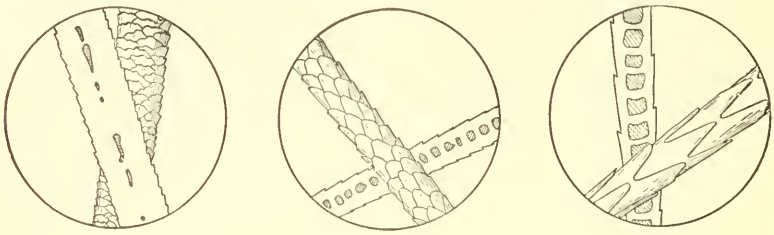


Fig. 118.—Fur Fibers. (10) Hair seal ($d = 105\mu$); (11) skunk ($d = 26\mu$); (12) wolverene ($d = 25\ \mu$.) (Hausman.)

ether-alcohol, as before, and then dipped with forceps into an alcoholic solution of Gentian Violet, Methyl Blue, Methyl Violet, Bismarck Brown,

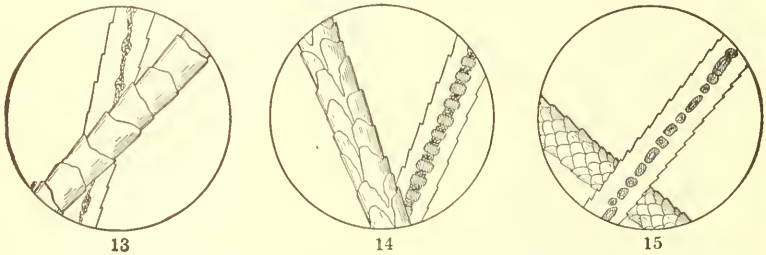


Fig. 119.—Fur Fibers. (13) Beaver ($d = 18\mu$); (14) chinchilla ($d = 16\mu$); (15) nutria, coney, hare, marmoset ($d = 11\mu$.) (Hausman.)

or Safranine. This treatment renders clear the outline of the scales. The following micrographs of various furs have been adapted from Haus-

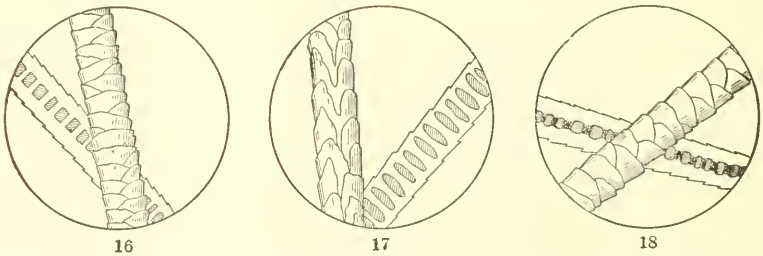


Fig. 120.—Fur Fibers. (16) Gray squirrel ($d = 18\mu$); (17) rabbit ($d = 17\mu$); (18) woodchuck ($d = 22\mu$.) (Hausman.)

man's article on this subject (see Figs. 115 to 127). As these are drawn to the same size instead of to the relative diameters of the fibers, these latter are given in terms of microns.

According to Hausman, the various colors of animal hairs are due either to pigment materials within the shaft, or to coloring matter deposited on

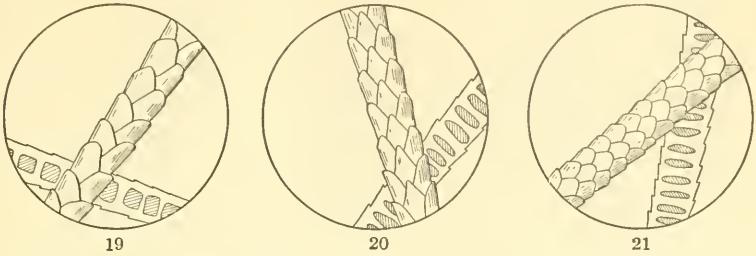


FIG. 121.—Fur Fibers. (19) Muskrat ($d=17\mu$); (20) European mole ($d=17\mu$); (21) American mole ($d=17\mu$.) (Hausman.)

the outside of the cuticle, and may be modified by the way in which the light is reflected from the surfaces of the various structures of the hair

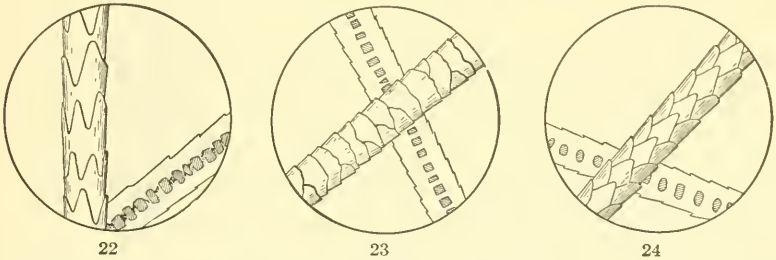


FIG. 122.—Fur Fibers. (22) Koala ($d=22\mu$); (23) opossum ($d=37\mu$); (24) duckbill ($d=18\mu$.) (Hausman.)

shaft itself. Hair which owes its hue to the latter cause is rare, being found, for example, on the flanks and base of the tail of the weasel. In the great

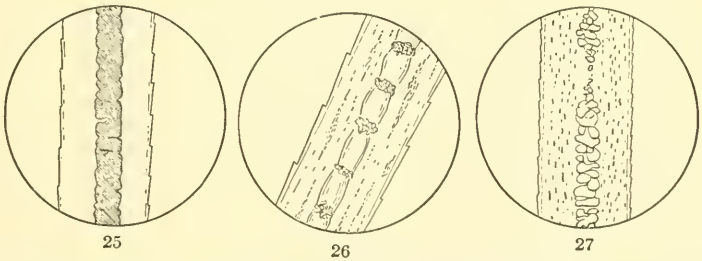


FIG. 123.—Fur Fibers. (25) Polar bear ($d=52\mu$); (26) black bear ($d=46\mu$); (27) squirrel monkey ($d=47\mu$.) Hausman.)

majority of cases it is the presence of pigment within the hair shaft that gives color to the hair.

The pigment material within the hair shaft may be diffuse, i.e., not

present in the form of distinct masses, and if such is the case the whole shaft is homogeneously stained and the hair appears, even under the

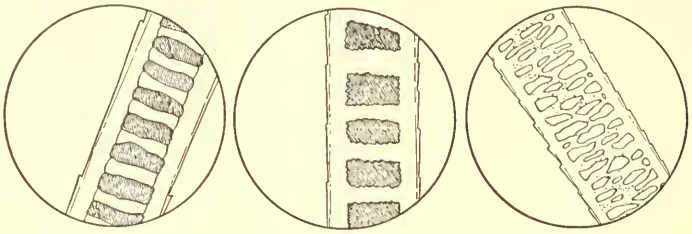


FIG. 124.—Fur Fibers. (28) Blarina ($d=38\mu$); (29) sewellel ($d=25\mu$); (30) guinea pig ($d=76\mu$.) (Hausman.)

highest powers of the microscope, as a uniformly colored structure. Yellow or amber hairs are usually pigmented in this way.

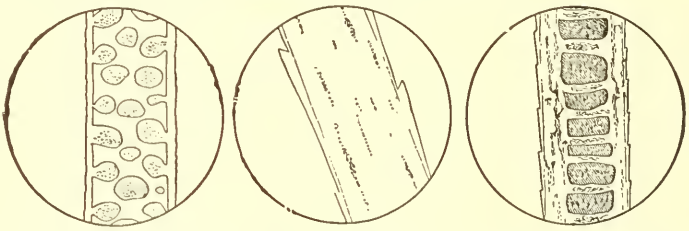


FIG. 125.—Fur Fibers. (31) Kangaroo rat ($d=40\mu$); (32) brown bat ($d=8\mu$); (33) marmoset ($d=25\mu$.) (Hausman.)

The most common cause of color in hair, however, is not external deposit, or internal diffuse stain, but the presence of pigment masses,

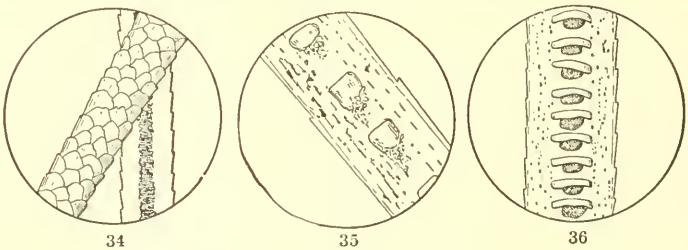


FIG. 126.—Fur Fibers. (34) Badger ($d=57\mu$); (35) weasel ($d=10\mu$); (36) blarina tip ($d=30\mu$.) (Hausman.)

occurring (1) in the cortex as separate granules, or (2) in the medulla, usually as amorphous masses, though sometimes as discrete granules.

The hair of the polar bear may be taken as typical of a pure white,

i.e., colorless, hair. It will be seen that no pigment is present in the cortex of such a hair, which appears under the microscope as a transparent, glassy shaft. The medulla appears to be dark in color. This is due, possibly, to a slight amount of black pigment in the fused medullary cells, but more largely to the dispersion of light from the microscope mirror.

In most instances the colors in hair are produced by a combination of cortical and medullary pigmentation, sometimes with the addition of diffuse color as well. In the hair of the black bear, for example, the color is due to very dark brown cortical granules, plus black medullary masses. Light brownish or yellowish cortical granules, plus dark brown medullary masses, produces dark brown fur, as in the New York weasel (Fig. 126, No. 35). The tip of the fur hair of the large blarina (Fig. 126, No. 36) shows the usual pigmentation conditions in a dark grayish brown hair, i.e., black medullary masses, and some few light brown cortical granules. Hair from the squirrel monkey (Fig. 123, No. 27) and marmoset (Fig. 125, No. 33), respectively, illustrate the typical conditions found in yellow or yellowish hairs, i.e., yellow granules both in medulla and cortex, or yellow granules in cortex, and yellow masses in the medulla.

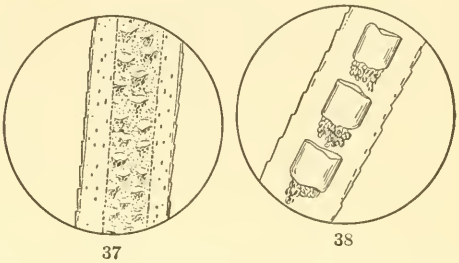


FIG. 127.—Fur Fibers. (37) Prairie dog ($d = 50\mu$); (38) cotton-tail rabbit ($d = 10\mu$.) (Hausman.)

The pigmentation in the fur hair of a species often differs from that in the protective hair. There is likewise a change in the character of the pigmentation from the base to the tip of both varieties. The nature of these pigmentation differences in the hairs of the same animal can be well illustrated from the hair of the muskrat.

CHAPTER IX

SILK: ITS ORIGIN AND CULTIVATION

1. Origin of Silk Fiber.—The silk fiber consists of a continuous thread which is spun by the silkworm. The worm winds the fiber around itself in the form of an enveloping cocoon before it passes into the chrysalis or pupal state. The cocoon is ovid in shape and is composed of one continuous fiber, which varies in length from 350 to 1200 meters (400 to 1300 yds.), and has an average diameter of 0.018 mm. In the raw state the fiber consists of a double thread cemented together by an enveloping layer of silk-glue, and is yellowish and translucent in appearance. When boiled off or scoured these double threads are separated, and the silk then appears as a single, lustrous, and almost white fiber.

Unlike both wool and cotton, silk is not cellular in structure, and is apparently a continuous filament devoid of structure. Höhnel, however, believes that the silk fiber is not so simple in structure as would at first be believed. The surface of the fiber frequently shows faint striations, which may be rendered more apparent by treatment with chromic acid. Also by saturating the silk with moderately concentrated sulfuric acid and drying, then heating to 80° to 100° C., the fiber will be disintegrated into small filaments, which would seem to indicate that it was made up of a number of minute fibrils firmly held together.

The silk industry is divided into a number of independent enterprises:

(*a*) Sericulture, which has to do with the growth and cultivation of the silkworm and the cocoon.

(*b*) Silk-reeling, in which the silk thread is wound from the cocoon into skeins known as raw silk of trade.

(*c*) Throwing, which takes the raw silk and converts it into suitable yarns for manufacturing purposes. The operator is known as a "throwster."

(*d*) Manufacturing, in which the thrown silk is made into various fabrics by weaving, knitting, braiding, etc., and also bleached, dyed, and weighted.

It seldom happens that any of these groups overlap in the same factory, but each operation is carried out as a separate industry.

2. History of Silk Culture.—The silk industry appears to have had its origin in China, and historically it dates back to about 2700 years B.C.

In its early history it is said that the art of cultivating the silkworm and preparing the fiber for use was a strictly guarded secret known only to the royal family. Gradually, however, it spread through other circles and soon became an important industry distributed universally throughout China. The Chinese monopolised the art for over three thousand years, but during the early period of the Christian era the cultivation of the silkworm (or sericulture) was introduced into Japan. It also gradually spread throughout central Asia, thence to Persia and Turkey. In the eighth century the Arabs acquired a knowledge of the silk industry, which soon spread through all the countries influenced by the Moorish rule, including Spain, Sicily, and the African coast. In the twelfth century we find sericulture practiced in Italy, where it slowly developed to a national

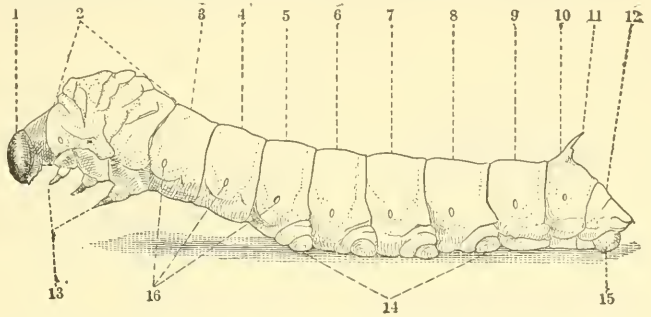


FIG. 128.—The Silkworm. (1) Head; (2–10), (12) rings; (11) horn; (13) articulated legs; (14) abdominal or false legs; (15) false legs on last ring.

industry. In France sericulture appears to have been introduced about the thirteenth century, but it was not until the reign of Louis XIV that it assumed any degree of importance. In more recent times experiments have been made on the cultivation of the silkworm in almost every civilised country.[1]

Mr. Samuel Whitmarsh, about 1838, made an attempt to introduce sericulture in America. He cultivated the South Sea Island mulberry (*Motus multicaulis*) in Pennsylvania, but the experiment proved to be a failure. Previous to this time there had been various sporadic attempts toward sericulture in America, and bounties were offered by various

[1] The word silk, as expressed in different languages, is as follows:

Korean	Sir	Danish	Silcke
Chinese	Se	Anglo-Saxon	Siolc
Mongol	Sirkek	English	Silk
Armenian	Cheram	Italian	Seta
Arabic	Seric	German	Seide
Latin	Sericum	French	Soie
Slavonian	Chelk		

States. In 1619 bounties were offered to Virginia settlers, and later Franklin at Philadelphia reared quite a promising filature. In later years there have been many attempts to introduce the industry of sericulture into the United States, and it has been satisfactorily demonstrated that good silk can be raised in this country, more especially in the Southern States. The failure of the industry has not been due to lack of proper climatic conditions, but simply to the high cost of labor as compared with Oriental labor. Even in 1921 it was reported that silk was being grown in southern California, and the claims were made that it would be possible to produce sufficient silk to cover the demands of America more profitably than by importing, notwithstanding the cheap Eastern labor. It is said that the climate of the foothills of the Sierras inhibits silkworm diseases and that the fiber is longer and more lustrous than the Japanese. With the elevation of labor costs in the Orient it may be quite possible in time to establish sericulture on a profitable scale in America.[1] With respect to the amount of raw material consumed, the United States stands first among the silk manufacturing countries of the world.

3. The Silkworm.—The silkworm is a species of caterpillar, and though there are quite a number of the latter which possess silk-producing organs, the number which secrete a sufficient quantity of the silk substance to render them of commercial importance is rather limited. The true silkworms all belong to the general class *Lepidoptera,* or scale-winged insects, and more specifically to the genus *Bombyx.* The principal species is the *Bombyx mori,* or mulberry silkworm, which produces by far the major portion of the silk that comes into trade.[2]

According to the number of the generations they produce in a year, the *Bombyx mori* are divided into two classes: the members of the one reproduce themselves several times annually, and are termed *polyvoltine;* their cocoons are small and coarse. The other worms have only one generation in a year, and hence are termed *annual.* The cocoons of the latter are much superior to those of the former.

There are two kinds of silkworm culture: One for production and one

[1] Balbiani (*Bull. des. Soies et Soieries,* 1921, p. 5) calls the attention of the Italian and the French silk world to the establishment of silk raising in California. So successful, he says, have been the experiments on the Pacific Coast that a company with a capital of $300,000 has been formed to continue them. A tract of land, amounting to about 800 acres, has been acquired at Oroville, Butte County, near Sacramento, for a mulberry plantation. He considers the samples to be equal to the best Italian, a view shared by some experts in the East. The company is believed to be employing Japanese instructors and is building a filature of 80 basins. In view of these developments, he urges Italian silk growers to encourage the production of silk in all directions in order to raise the industry to its former state.

[2] Wardle (*Tussur Silk,* p. 40) gives a list of several hundred species of *Lepidoptera* that yield silk.

for breeding. The object in the first case is to get the greatest yield of cocoons, and with a little training this enterprise may be carried on by any one of ordinary intelligence. The object in culture for breeding is to secure eggs free from hereditary taint of disease, and experts only can be depended on for this culture. Besides a careful physiological examination throughout the rearing, the body of the mother moth is microscopically tested after death, and her eggs are not retained if signs of disease are discovered. In this way the birth of healthy worms is insured. Pasteur first applied this method of selecting silkworm eggs, and thus checked

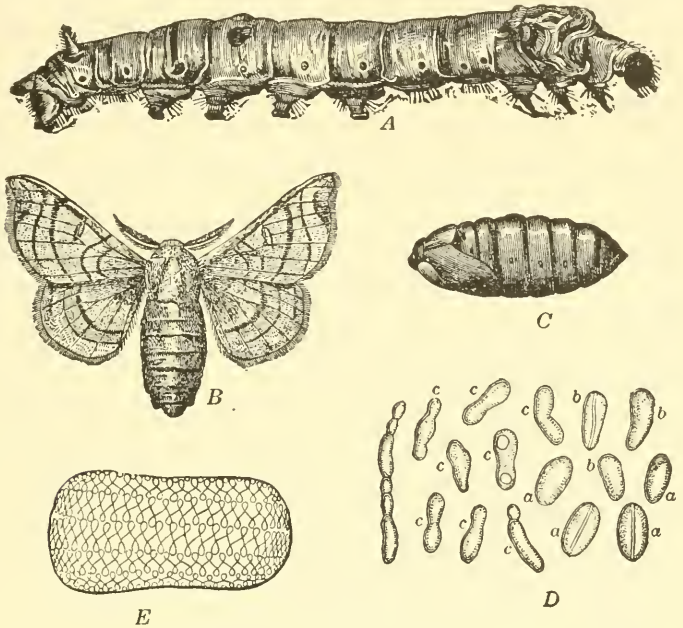


FIG. 129.—Showing Different Stages in Growth of Silkworm. *A*, Silkworm in fifth period, full size; *B*, moth or butterfly; *C*, chrysalis, or pupa; *D*, eggs of moth; *E*, diagram showing cocoon and method of winding.

the plague (pebrine) which was rapidly destroying silkworm culture in Europe.

The cultivation of the silkworm starts with the proper care and disposition of the eggs. With the annual worms there elapse about ten months between the time the eggs are laid and their hatching. The hatching only takes place after the eggs have been exposed to the cold for some time and are subsequently subjected to the influence of heat. When the eggs are laid by the silk-moth they are received on cloths, to which they stick by virtue of a gummy substance which encloses them. For the first few days they are hung up in a room, the air of which is kept at a certain

degree of humidity—about semi-saturation. Then comes a period of hibernation, during which the eggs are kept in a cool place; at present artificial refrigeration is resorted to in many establishments. The period of hibernation lasts about six months. After this comes the period of incubation, in which the embryo is gradually developed into a worm and the egg is hatched. The hatching usually takes place in heated compartments, in which the temperature is carefully regulated. The period of incubation occupies about thirty days, though this time has been shortened considerably by certain artifices, such as the action of electric discharges. Twenty-five grams of eggs will yield about 36,000 worms on hatching.

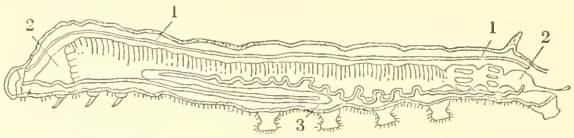


FIG. 130.—Section through the Silkworm.

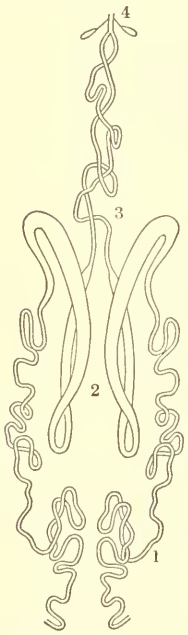


FIG. 131. — Silk-producing Gland of the Silkworm.

The caterpillar, on first making its appearance, is about 3 mm. long, and weighs approximately 0.005 gram. Its growth and development proceed with extraordinary rapidity, and during its short existence it undergoes a number of very curious transformations. Under normal conditions there elapse thirty-three to thirty-four days between the time of the hatching of the egg and the commencement of the spinning of the cocoon. During this time the worm sheds its skin four times, and these periods of moulting divide the life-history of the worm into five periods. The length of time occupied in these different ages approximates as follows:

1st, from birth to first moult, 5 to 6 days.
2d, from first to second moult, 4 days.
3d, from second to third moult, 4 to 5 days.
4th, from third to fourth moult, 5 to 7 days.
5th, from fourth moult to maturity, 7 to 12 days.

Almost immediately after being hatched the worms commence to devour mulberry leaves with great avidity, and continue to eat throughout the five periods, though, when about to shed their skins, they stop eating for a time and become motionless.

The size and weight of the caterpillars increase with remarkable rapidity; during the fifth period they reach their greatest development, measuring from 8 to 9 cm. in length (Fig. 128) and weighing from 4 to 5 grams, and after thus maturing they begin to diminish in weight. The following table by Vignon shows the relative weights of the silkworm

during the different stages of its existence. The figures refer to the weight of 36,000 worms.

	Grams.
Eggs	25
Worms (36,000)	17
First period (5 to 6 days)	255
Second period (4 to 5 days)	1,598
Third period (6 to 7 days)	6,800
Fourth period (7 to 8 days)	27,676
Fifth period (11 to 12 days)	161,500
At maturity	131,920
Cocoons	76,250
Chrysalis alone	66,300
Butterflies, half of each sex	99,865

Thus we see that in less than forty days the weight of the silkworm increases almost 10,000 times.

According to Arbousett 1 oz. of silkworm seed (eggs) produces about 30,000 silkworms, and these will yield a harvest of 130 to 140 lbs. of fresh cocoons, giving an ultimate yield of about 12 lbs. of reeled raw silk. These worms in their growth consume about 1 ton of ripe mulberry leaves.

When the worm has reached the limit of its growth, it ceases to eat, and commences to diminish in size and weight. The time is now ready for the spinning of its cocoon; the worm perches on the twigs so disposed to receive it and exudes a viscous fluid from the two glands in its body wherein the silk secretion is formed. The liquid flows through two channels in the head of the worm into a common exit-tube, where also flows the secretion of two other symmetrically situated glands which cements the two threads together. Consequently, the thread of raw silk is produced by four glands in the worm; the two back ones secrete the fibroine which gives the double silk fiber, while the two front glands secrete the silk-glue or sericine which serves as an integument and cementing substance. On emerging from the spinneret in the head of the worm the fiber coagulates on contact with the air.

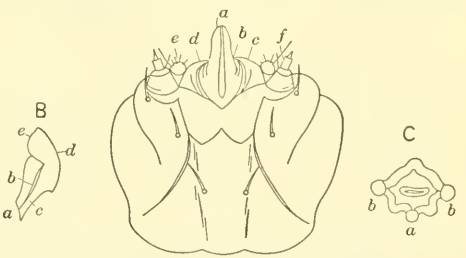


Fig. 132.—Outside Appearance of Spinneret of Silkworm.

According to Bolley the glands in the silkworm which secrete the fiber-producing liquids contain only glutinous, semi-fluid fibroine without admixture with sericine, the latter compound being a product of the subsequent oxidation of the fibroine by the air.

The viscous liquid in the glands of the silkworm is utilised in a peculiar manner for the preparation of silkworm gut for fishing lines, or for other such purposes where lightness, tenacity, flexibility, and great strength are essential. The fully developed larvae are killed and hardened by steeping for several hours in acetic acid; the glands are then removed and their viscous contents are drawn out to a fine uniform line which is stretched between pins on a board. This is then exposed to sunlight until the lines dry into the condition of gut. This is a rather unimportant, though interesting collateral branch of silk manufacture.

The contents of the glands of the silkworm have been the subject of study in a peculiar manner by Chappe. He triturated the glutinous matter with about one-third its weight of water, and thus obtained a liquid from which he was enabled to blow variously shaped vessels of a very permanent character.

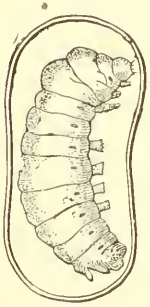


Fig. 133.

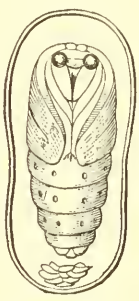


Fig. 134.

Fig. 133.—Silkworm at Completion of Cocoon.

Fig. 134.—After Development of Chrysalis with Cast-off Skin of Larva Beneath.

A rather unusual silk fiber is that known as "Fil de Florence"; it is said to have been known in China from a very early date, though first mentioned in Europe in 1760. The fiber is not prepared from the cocoon of the silkworm, but from the silk-containing organs of the worm itself. The worm is soaked in acetic acid, opened, and the silk glands, which are about 2 ins. long, are removed. These are stretched while soft to a length of about 15 to 20 ins.

4. The Cocoon.—The worm weaves the thread around itself, layer after layer, until the cocoon or shell is gradually built up. It requires about three days for the completion of the cocoon. First a net is formed to hold the cocoon which is to be spun, then the regular spinning begins and the form of the cocoon is designed. It is calculated that with its head alone the silkworm makes 69 movements every minute, describing arcs of circles, crossed in the form of the figure 8. Meanwhile the web grows closer and the veil thickens, and in about 72 hours the worm is completely shut up in its cocoon, which serves it as a protective covering.

After finishing the winding of its cocoon, the enclosed silkworm undergoes a remarkable transformation, passing from the form of a caterpillar into an inert chrysalis or pupa, from which condition it rapidly develops into a butterfly, which then cuts an opening through the cocoon and flies away. The worm in spinning the cocoon leaves one end less dense, so

that the threads open freely to permit the egress of the moth. By the aid of an alkaline fluid the moth softens and parts the threads and liberates itself.

As the integrity of the cocoon thread would be destroyed by the escape of the butterfly and hence lose much of its value, it is desirable that the development of the chrysalis be stopped before it proceeds too far, and this is accomplished by killing it by a heat of from 70° to 80° C. or by live steam. The cocoons at this stage weigh from 1.25 to 2.5 grams each, and of this 15 to 16 percent is silk fiber. The proportion of silk in a cocoon varies according to the race and also to the regimen to which the worm has been subjected. The average normal cocoon at the time it is sold is thus composed:

	Percent.
Water	68.2
Silk	14.3
Web and veil	0.7
Chrysalis	16.8

However, only 8 to 10 percent is available for silk filaments, the remainder, 6 to 7 percent, constituting waste and broken threads, and is utilised for spun silk.

As to the thickness of the filaments of silk in the cocoon, Haberlandt furnishes the following data:

Species.	Exterior Layer of Cocoon.	Middle Layer.	Interior Layer.
Yellow Milanais	0.030 mm.	0.040 mm.	0.025 mm.
Yellow French	0.025 "	0.035 "	0.025 "
Green Japan	0.030 "	0.040 "	0.020 "
White Japan	0.020 "	0.030 "	0.017 "
Bivoltin worms	0.025 "	0.035 "	0.020 "

5. The Cocoon Thread.—The double silk fiber as it exists in the cocoon is known as the *bave*, and the single filaments are called *brins*. These terms are not common in the American trade, where the unprocessed cocoon thread is seldom used; they are mostly to be found in the trade parlance of the European silk industry. The size of the double silk fiber as it comes from the cocoon averages $2\frac{1}{2}$ to 3 deniers. The following table gives the approximate size of cocoon threads of mulberry silk from different countries:

Country.	Weight of 500 Meters.	
	In Deniers.	In Milligrams.
Spain	3.0	163
France	2.6	138
Italy	2.4	128
Syria	2.4	128
Caucasus	2.3	125
Broussa	2.2	117
Japan	2.1	113
China	2.0	108
Bengal	1.2	64

The single silk filament in the double cocoon thread, therefore, is about $1\frac{1}{4}$ to $1\frac{1}{2}$ deniers in size.

According to the Lyons Conditioning House, the average size of cocoon threads is given as follows:

	Deniers.
Yellow Piedmont	3.06
" Cevennes	3.03
White Persians	2.87
Yellow Adrianople	2.84
" Tuscan	2.81
" Salonika	2.73
" Greece	2.61
" Hungarian	2.64
White Turkestan	2.68
" Japanese	2.12
" Chinese	1.96

The highest grade of silk is the white or yellow Italian silk raised in Piedmont, together with the best China silks reeled in steam filatures. The next grade is the best Japan silk. There is, however, much low-grade silk sent out of Italy. Most of the cocoons grown in Asia Minor and Turkey-in-Europe are sent to Italy for reeling. The French Cevennes silks are of good quality but are more hairy in nature than generally desirable. Canton silks come from South China, and are soft, lustrous, and very hairy, on which last account their use is rather limited. White China silks reeled in the native fashion are known as Tsatlees and are too irregular to be generally useful. Both Tsatlees and Cantons are difficult to throw and the throwing cost is 5 to 10 cents per pound higher than for ordinary silks.

Bengal (Indian) silk is of poor quality and is only used for certain special purposes, such as for the making of silk hats and for some qualities of sewing threads.

Chittick (*Silk Manufacturing*, p. 18) points out that some silks have adherent disadvantages about them which must be remembered when considering the price. Thus Tsatlees, owing to their great irregularity in size and to the way in which they are generally reeled, not only cost more for throwing and in waste, but may require the use of more weight of material to give the proper cover. The amount of boil-off of the silk is also to be well considered, particularly in fabrics for piece dyeing, as it makes quite a difference whether the silk boils off 24 percent, as in the case of yellow Italian, or 18 percent, as in the case of Japanese silks.

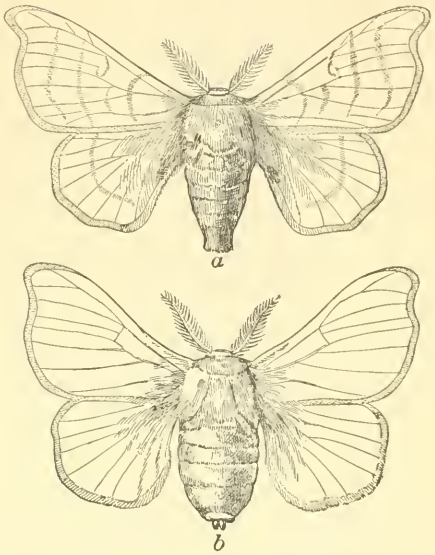


FIG. 135.—The Silk-moth. *a*, Male; *b*, female.

Murphy (*Textile Industries*, p. 63) gives the following table relative to different varieties of silk:

Silkworm.	Country.	Diameter of Fiber, 1/1000 Ins.		Tensile Strength, Drams.		Feed.	Color.	Size of Cocoons, Ins.
		Outer.	Inner.	Outer.	Inner.			
Bombyx mori	China	53	71	1.6	2.6	Mulberry	White	1.1×0.5
B. mori	Italy	53	68	1.9	2.6	"	"	1.2×0.6
B. mori	Japan	57	69	2.0	3.1	"	"	1.1×0.6
B. fortunatus	Bengal	45	51	1.6	2.8	"	Golden yellow	1.2×0.5
B. textor	India	42	47	1.4	2.6	"	White	1.2×1.5
Anth. mylitto	"	161	172	6.6	7.8	Seemul	Brown	1.5×0.8
Attacus ricinus	"	85	93	1.5	3.0	Castor oil tree	Orange	1.5×0.8
A. cynthia	"	83	97	2.4	3.5	A. glandulosa	Yellowish	1.8×0.8
A. atlas	"	102	111	2.1	4.1	Omnivorous	White	3.5×0.8
Actias selene	"	100	109	2.4	4.0	Cherry	Grayish	3.0×1.2
Anth. pernyi	China	118	138	3.2	5.8	Oak	Brown	1.6×0.8
Yama-mai	Japan	88	96	6.8	7.5	Wild oak	Bluish	1.5×0.5

Raw silk is classified on the New York market as follows:

European silks:		
Grand Extra		Best No. 1
Extra Classical		No. 1
Best Classical		Realine
Classical		
Japan silks:		
Filature.	Re-reels.	Kakeda.
Double Extra	Extra	Best Extra
Extra	No. 1	Extra
Sinshiu Extra	No. 1–1½	No. 1
Best No. 1, Extra	No. 1½	No. 2
Best No. 1	No. 1½–2	No. 3
Hard Nature No. 1	No. 2	
No. 1, Summer Reeling	No. 2–2½	
No. 1–1½	No. 2½	
No. 1½	No. 3	
No. 1½–2		
No. 2		

Japan silk is not as white in color as China silk; in the low grades it is more or less streaky and discolored, which is apt to cause shadiness in the dyed piece. The strength and elasticity vary widely; the brilliancy is as good as that of Chinese silk or the high-class European silks. Japanese silks are also distinctly irregular in size as compared with the better qualities of European silks.

6. Waste Silk.—There are several different varieties of waste silk, as follows:

1. The refuse obtained in raising the silkworm, called watt silk in commerce. Owing to the scientific methods of silk-culture in Europe, the amount obtained from this source is very small. China, however, exports a large amount yearly. This material contains about 35 percent of pure silk, and is the poorest grade of waste silk on account of its irregularity.

2. The irregularly spun and tangled silk on the outside of the cocoon, called floss silk or frisons. It comprises from 25 to 30 percent of the entire cocoon, and is valuable owing to its purity and fine quality.

3. The residue of the cocoon after reeling; this forms an inner parchment-like skin, and in commerce goes under the name of ricotti, wadding, neri, galettame, basinetto, etc.

4. Cocoons imperfect from various causes, such as being punctured by the worms, becoming spotted by pupa breaking, etc. These are known as cocoons, perces, piques, tarmate, rugginose, etc. It forms a valuable material for floss-silk spinning.

5. Double cocoons, which, in spite of the difficulty in reeling, were formerly used for special purposes. Now such cocoons are converted into waste which is known as strussa.

6. Waste obtained in reeling the cocoons, known as frisonnets.

7. A great variety of wild silks, which, for the most part, cannot be reeled, and are, therefore, first converted into waste. A large quantity of wild silk, even though it can be reeled, is torn up for waste.

8. Waste made by throwing, spooling, and other processes of working silk. The waste in throwing varies with the character of the raw silk. According to Chittick, the following wastage is to be expected:

	Percent.
Regular organzine	1.75–2.50
Regular tram	1.75–3.00
Canton tram	4.25–6.00
Crack tussah chops	3.50
Lower grade	5.00
Press-packed tussahs	7.50–10.00
Crèpe twists	2.00– 3.00
Tsatlees	3.00– 5.00

Armitage (*Textile Manufacturer*) states that for practical purposes all the waste silk that can be used by a spinner may be classed under two heads: gum wastes and knub wastes. *Gum waste* is the product of the reeler and thrower of nett silk. The best classes of cocoon are reeled and thrown, and it follows that the waste produced is the best waste. It is long, strong, and lustrous. *Knub waste* consists largely of that part of the cocoon which is considered to be of too poor a quality to reel; also the outer covering and the inner shell of the cocoon are of poorer quality than the intermediate part.

Foremost among gum wastes must be placed what is known as China waste. It is of three grades—English, French, and Italian. It is obtained from China raw silk, and is named according to the country in which the silk is thrown. French and Italian China are best. The English differs from the French and Italian in the particular that the English throwsters soap their nett silk in throwing; hence the waste is of duller appearance, and contains a percentage of soap, which gives it the appearance of inferiority, as against the bright and clear product of the French and Italian throwster. The chief excellences of China waste are whiteness, brightness, length, and strength of fiber. It is especially valuable for spinning the finest counts, such as 120–2 and 100–2.

Nankin buttons is another waste of merit. It is a product of Central China. It derives its name from the fact that it contains a proportion of matted silk formed so as to appear similar to a button. It is white and bright, but irregular in length and is subject to hard ends, which are so tightly twisted together that they cannot be split into fiber and dressed and drawn as the spinner desires.

Shanghai waste is another gum waste that is largely used. It is in two grades—fine and coarse, white and yellow. The white is mostly used, and is shipped as Hangchow, Chintzar, etc. It is excellent waste, but not so good in color as China or Nankin, and is much more liable to impurities. Yellow Piedmont and Italian wastes are also largely used. They are

bright and strong, and usually free from objectionable matter, but produce a creamy colored yarn.

French gray and *yellow waste* have great merit. Either yields well, is bright and long, but is invariably subject to cotton ends. These in the course of subsequent processes are broken up, and the result is disastrous. When the yarn leaves the dyer it is specky and flecky; the cotton shows white, and unsatisfactory goods are the result.

Canton gum re-reeled is a waste of great luster, but in other respects is not so good as the before-mentioned wastes. It is made from Canton raw silks that are re-reeled in order to take out the thick and uneven places left in the silk at the first reeling. Canton gum is a fairly bright waste, but is subject to twisted ends, hemp and black hairs, and can be used only for low-class yarns.

Punjum waste is a peculiar waste of great strength and luster. It is produced from cocoons of coarse and uneven texture, and in reeling the ends off, from 6 to 12 cocoons are taken up and reeled together, no attention being given to straightness. It is very heavily gummed, in some cases to the extent of 50 percent.

Indian gum wastes are the despair of the spinner. They contain good, fine waste mixed with the coarsest qualities produced. They contain about 10 percent cotton, twist, hairs, string, and other abominations.

Steam waste is the finest and best knub waste, and is the foundation waste of the spinner. It is imported in various grades, and in two distinct sorts: unopened and opened. This waste is produced in the native reeling mills of China. The reeling is done by steam power, and the cocoons are softened in water, and treated by steam; hence the designation "steam waste." The wet waste made in reeling is thrown on to the floor, and the gum hardens again and forms the silk into hard knubs or balls. These are collected and put into bales for shipment as unopened steam waste.

Opened steam waste is waste that has been pulled into a loose state by the natives, who use their fingers and teeth for the purpose.

China curlics is another Shanghai waste very nearly allied to steam waste. Each exporter has his own mark or *chop*, such as "yellow pony," "double fighting cock," "golden lion," etc. It is a good waste, rather longer than steam waste, and a little brighter and stronger.

Kikai kibbizzo, or Japan curlies, is another waste of great merit. It is shipped from Yokohama. It is a good color, yields well, and is generally of better quality than either steam waste or China curlies. It is not a lustrous waste, but it is lofty and gives body to the yarn.

Iwashiro noshi is another Japan waste of superior quality, but it can be obtained only in small quantity.

Noshito joshim is the lowest quality of Japan waste that can be used by spinners, but it is scarcely worth attention.

There are several wastes of good quality produced in Persia, Syria, and Turkey, but they can be had only in comparatively small quantity, and are used only by a few spinners for particular purposes.

Tussah waste is a product of China, and is of a golden-brown color and of coarse fiber. It is long, strong, and lustrous, and makes a splendid yarn. Owing to its color its uses are somewhat restricted. The yarn made from this waste is used largely for seal plushes, for which it is well suited. The strength of the fiber gives a spring in pile goods that cannot be obtained from the finer white silks.

Before preparing the waste for the subsequent processes, careful discrimination is necessary in determining the class of waste best suited for the branch of trade to be catered to. For example, the best yarn for the sewing silk trade cannot be obtained from steam waste alone. Sewing silk needs to be hard, level, bright, and strong; consequently, the best results will be obtained from wastes possessing, in a most marked degree, these qualifications. For damask yarns steam waste and China curlies make an admirable combination. For sewing silk, China, Italian, Piedmont, and French waste, and long knub, are very suitable, either or all of them; but care must be taken to get out the cotton. For hosiery yarns of the best grades the same wastes as for sewing silks are suitable, as, although the yarns are quite different in point of twist and make-up, they require to be bright and smooth and free from neps or slubs. As a second grade, good steam waste and medium-quality gum waste will be useful. For lace yarns, best quality good gum wastes should be used, and for the lower-class trade steam waste and curlies, with medium gum wastes, are the correct thing. For the ordinary embroidery and tassel trade a fairly low class of either gum or knub waste, or a combination of both, will do; but care must be taken practically to free the waste of matter that will not take a silk dye. The high class embroidery and filoselle trade need the best gum waste and knub waste obtainable, and these must be free from cotton.

For plushes, punjum waste is absolutely unapproachable, owing to its strength and luster and the rigidity of the cut fiber. Another quality for plushes can be made with good effect from a mixture of medium gum waste and knub waste. For dark shades of plush, Tussah waste is the ideal fiber.

Great care should be exercised in selecting wastes for making a blend, and as nearly as possible they should be of the same class. For instance, steam waste and China waste should never be mixed and dressed together. They require different treatment in the dressing owing to the difference in the length and strength of the fiber.

7. Silk Noil and Shoddy.— Silk noils consist of the short fibers resulting from the combing of spun silk. These noils are themselves combed and

spun into coarse yarns on special machines, and the yarn so obtained is principally used in the manufacture of powder bags for big guns. Silk noils are also utilised by mixing with wool for the preparation of fancy yarns for dress goods.

Silk shoddy resembles wool shoddy in origin, consisting of recovered fibers from manufactured silk goods. It nearly always contains isolated fibers of both wool and cotton, and frequently mixtures of different kinds of silk. There may also occur boiled-off, soupled, and raw silk, and mixtures of organzine and spun silk. Different colors are also usually present. The fibers, as a rule, are quite short, being about a centimeter in length. Due to these components, silk shoddy is comparatively easy to recognise under the microscope.

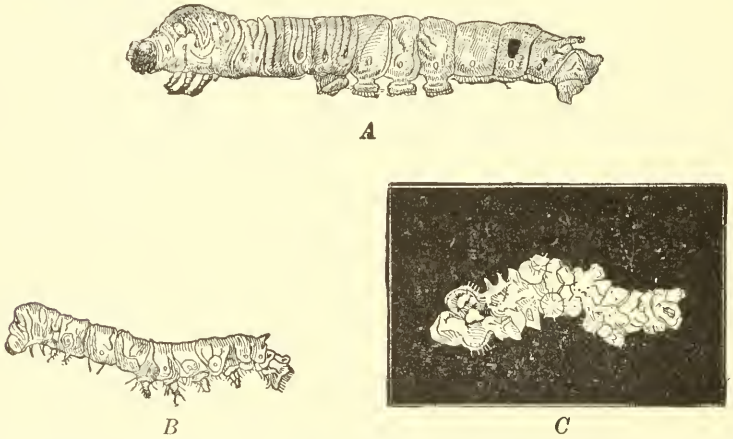


FIG. 136.—Diseased Silkworms. *A*, Worm afflicted with flacherie; *B*, worm emaciated by gattine; *C*, calcinated worm. (After *Silkworm Culture.*)

8. Diseases of the Silkworm.—The silkworm is particularly liable to contract various diseases, which become more or less epidemic in character. In the early history of sericulture in Europe the industry was frequently threatened with almost total destruction by the widespread ravages of certain diseases of the silkworm. The French chemist Pasteur devoted much attention to this subject and succeeded in devising means of avoiding or preventing almost all such diseases. The principal diseases of the silkworm are the following:

(*a*) *Pebrine.*—Worms afflicted with this disease develop slowly, irregularly, and very unequally. Black spots are the most marked outward characteristics: the internal signs are oval corpuscles visible only under the microscope. There appears to be no remedy for this disease, but Pasteur found it could be prevented by a microscopical selection of the eggs, and at the present day it causes but little trouble among silk-growers. Between 1833 and 1865 the annual crop of cocoons in France was reduced by pebrine from 57,200,000 lbs. to 8,800,000 lbs. It was first noticed in epidemic

form in France in 1845, but since then has spread throughout Asia Minor and the Orient.

(*b*) *Flacherie* (or flaccidity) is at present the most dreaded disease among European silkworms. It usually affects the worm after the fourth moult, or even while spinning. Without apparent cause the worms begin to languish and shortly die. After death they turn black in color and emit a disagreeable odor. Flacherie is apparently a form of indigestion, and may be induced by micro-organisms in the intestinal canal of the worm. Contagion is usually prevented by dipping the eggs in a solution of copper sulfate, and as the micro-organisms causing flacherie persist alive from year to year, very careful fumigation must be instituted whenever this disease develops.

(*c*) *Gattine* shows itself externally by indifference of the worm to food, torpor, and generally emaciation. It usually affects the worm in the early ages, though it is sometimes associated with flacherie. The best preventive against both flacherie and gattine is a careful selection of healthy eggs.

(*d*) *Calcino* (or muscardine) at first does not exhibit any external characteristics, but the vitality of the worm is slowly impaired and it feeds and moves but slowly. The body becomes reddish in color, and gradually contracts and loses its elasticity, and the worm usually dies 20–30 hours after the first symptoms of the disease. The dead body dries up and becomes covered with a white chalk-like efflorescence. The disease is caused by a minute fungus, the spores of which take root in the body of the worm, and finally fill the entire body. There are two varieties of this fungus: *Botrytis bassiana* and *B. tevella*. The white chalk-like appearance of the dead worm is caused by the branches of the fungus fructifying on the surface, and the fruit bursting envelops the worm with innumerable spores resembling a white powder. Calcino is the most contagious of the silkworm diseases, and its appearance should be promptly checked by careful fumigation with burning sulfur.

(*e*) *Grasserie* shows itself by the worms becoming restless, bloated, and yellow in color, and when punctured they exude a fetid matter filled with minute granular crystals. The disease is not caused by microbes, hence is neither contagious nor hereditary. Its chief cause is mismanagement of the worms at moulting periods and uneven feeding.[1]

9. Wild Silks.—Besides the *Bombyx mori*, or mulberry silkworm, there are other associated varieties of caterpillars, which also produce silk in sufficient quantity to be of considerable commercial importance. Due to the fact that such silkworms are not capable of being domesticated and artificially cultivated like the mulberry worms, the silk obtained from them is called wild silk. Of this latter there are several commercial varieties, of which the most important are here given.

Antheræa yama-mai, a native of Japan, is a green-colored caterpillar which feeds on oak leaves. Its cocoon is large and of a bright greenish color. The silk bears a close resemblance to that of the *Bombyx mori*, but is not as readily dyed and bleached as the latter.

[1] Grasserie is frequently attributed to infection by a microbe as yet unknown. Mr. Lambert, the Director of the sericultural station at Montpelier, has shown that the disease may be produced by feeding the worms on the leaves of the water-caltrop, which they will eat as readily as mulberry leaves. As a matter of fact, unsuitable feeding seems to produce the disease, which Mr. Lambert believes to be allied in some obscure fashion to flacherie.

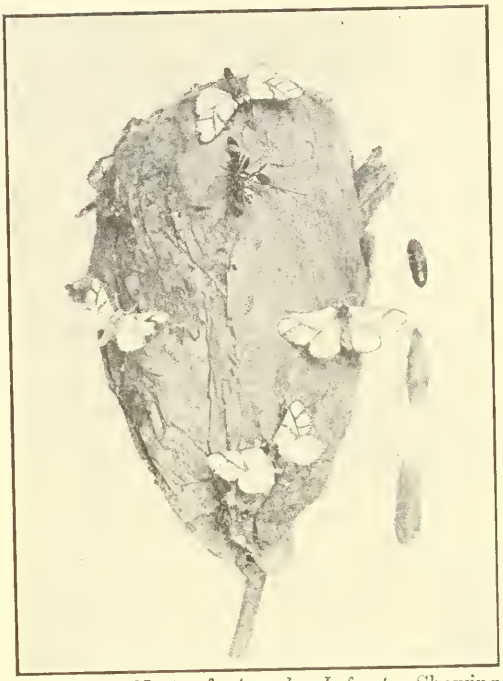


FIG. 137.—Nest of *Anaphe Infracta*, Showing Moths, Single Cocoons and Chrysalis.

Antheræa pernyi is a native of China; besides growing wild, it has been domesticated to some extent. This worm also feeds on oak-leaves, but is of a yellow color. Its cocoon is quite large, averaging over 4 cm. in length, and is of a yellowish to a brown color.

Antheræa assama is a native of India; it gives a large cocoon over 45 mm. in length.

Antheræa mylitta is another Indian variety, and furnishes the so-called *tussah* silk, though this term has also been applied in a general manner to all varieties of wild silk. The worms feed on the leaves of the castor-oil plant, and give very large cocoons, reaching 50 mm. in length and 30 mm. in diameter. The fiber is much longer than from the cocoon of the *B. mori*, and varies from 600 to 2000 yards in length. The color of tussah silk varies from a gray to a deep brown.

Silbermann classifies the varieties of wild silkworms as follows:

(1) Those with closed cocoons containing fairly uniform silk threads which can be reeled without much difficulty: (*a*) Wild mulberry silkworms; (*b*) *Antheræa yama-mai;* (*c*) Tussah family; (*d*) *Moonga* family; (*e*) *Actias* family.

(3) Those with open cocoons containing silk threads which cannot be reeled: (*a*) *Attacus* family; (*b*) various other species.

(3) Various species of *Saturnidæ*, as yet of no technical value.

Another variety of silkworm which is to be found both in Asia and America is the *Attacus ricini*. It gives a very white and good quality silk, the production and value of which is increasing every

FIG. 138.—Nest of Anaphe Silk Cocoons.
A, Single cocoons; *B*, hard papery layer; *C*, coarse outer layers.

year. It is known as Eria silk. The structure of the fiber much resembles that of tussah silk. A species of this class, known as *Attacus atlas*, is perhaps the largest moth known; it spins open cocoons and gives the so-called Fagara, or Ailanthus, silk.

There is a silkworm found in Uganda and other parts of Africa belonging to the *Anaphe* species. It feeds principally on the leaves of a species of fig tree. The caterpillars construct large nests inside of which they form their cocoons in considerable numbers. The entire nest together with the cocoons is composed of silk, and the whole of the product is capable of being used for waste silk.[1] In southern Nigeria this anaphe silk is used by the natives in conjunction with cotton for making the so-called "soyan" cloths.

10. Tussah Silk.—According to J. K. Davis (*Consular Reports*) the silkworm producing tussah silk is known to the Chinese as the *shan tsan* or mountain silkworm, and scientifically has been variously classified by different authorities. Among the classifications given are *Antherea pernyi*, *Bombyx pernyi*, and *Bombyx fertoni*. Both in size and general appearance it is quite different from the silkworm which produces the better known white silk. On maturity it varies in length from 3 to 5 ins., and is of a soft green color, with tufts of reddish brown hairs at different parts of its body.

While the white silkworm must have the leaves of cultivated mulberry trees for its food, its less particular and more hardy northern cousin subsists on the leaves of several species of dwarf mountain oak which are native to eastern Manchuria, and grow uncultivated in great abundance on the sides of the otherwise rather unproductive hills that traverse this entire district. These trees serve the purposes of sericulture best when at a height of from 5 to 6 ft., and are accordingly kept from growing too tall by prunings made at intervals of several years. Where the natural groves are insufficient recourse is had to artificial planting from seed. This, however, is a slow process, since from four to seven years' growth is required to produce a tree useful for feeding, and the trees are not at their best until they are from twelve to sixteen years old.

Two crops of cocoons are produced annually, one in the spring and one in the autumn. The spring crop is put on the market early in July;

[1] The Imperial Institute has made an extensive investigation on the utilisation of anaphe wild silk. There is an outer layer or nest which contains the cocoons located within, and as this outer layer is more difficult to degum than the cocoons it is advisable to separate it from them and work it up for the fiber by itself. When the nests of the anaphe silk are handled in the dry state they cause an intense irritation of the skin and mucous membrane, presumably due to the enclosed hairs of the caterpillars; therefore, before the nests are separated from the cocoons they must be soaked in water, or better yet, it is advised to boil the envelopes for two hours in a 1 percent solution of sodium carbonate.

it is the smaller of the two, and is used principally to produce eggs for the autumn crop, which is usually marketed after the middle of October. The usual method of killing the chrysalides is by storing cocoons in large warehouses capable of being heated, and in the midst of the extreme cold season (in Manchuria) raising the temperature to that of a spring day for a period of several days, after which it is lowered to the outside atmospheric temperature again. When this process has been repeated several times the chrysalides are killed and the cocoons may then be carried over to the summer with no danger of being pierced.

Cocoons are prepared for reeling by a process of steaming, which serves to dissolve the secretion with which the component fibers have been fastened together. This process also kills the chrysalides in the case of the cocoons which have not been treated by the process just described. Steaming is done in large iron caldrons sunk into brick stoves, which are usually located in a room immediately adjoining that in which the reeling is to take place. The caldron is first filled with a solution made by dissolving in water approximately 6 to 8 ounces of soda for each thousand cocoons to be steamed, and after this mixture has been heated to the boiling point the cocoons are thrown in and rapidly stirred for several minutes. They are then dipped out and put into a round container, not unlike a deep sieve in appearance but with parallel strips of bamboo for a bottom, which is placed immediately over the caldron so that the bamboo slats are only an inch or more above the surface of the boiling solution, and in this position are steamed for several hours.

When the process of steaming has been completed the inextricable mass of tangled fibers which form the outer covering of the cocoons, and which is known as ta-wan-shu, or "big waste," is removed; the innermost fibers which actually enwrap the chrysalides are hopelessly tangled, and are known as the erh-wan-shu, or "second waste." From its nature waste cannot be reeled as is the thread, but must be chopped up, combed, carded, and spun. Heretofore waste has always been shipped to Europe for manufacture.

After the outer waste has been removed the cocoons are taken into the reeling room and distributed to the reel operators, who are usually arranged on high platforms running the length of a long, narrow room, one operator to a reel. Each operator then gathers the ends of the fibers of from 6 to 8 cocoons, twists them into a thread which he fastens to his reel, and by means of a treadle starts the reel revolving. As the thread passes through several rings before reaching the reel it is twisted, and is wound on to the reel in the form of the finished thread. The reels are of two sizes, one with a diameter of $1\frac{1}{2}$ ft. and the other $2\frac{1}{2}$, and in Antung are all operated by foot power.

The average capacity of an operator is from 700 to 900 cocoons a day

while the experts attain occasionally to 1200. The skeins, which are usually some 4 feet in circumference, are folded once and twisted spirally. The thread, when it has been manufactured into skeins in this manner, is known as "tussah."

The silk-producing qualities of the spring and autumn cocoons are different. One thousand spring cocoons will furnish from $5\frac{1}{3}$ to 8 ozs. avoirdupois of tussah, whereas the autumn cocoons yield from 8 to 12 ozs. The silk produced from the spring cocoons is of a softer and more pleasing texture than that from the later ones.

Tussah is classified by the Chinese trade into five grades, known as "extra," "No. 1," "No. 2," "No. 3," and "No. 4," according to quality. It is also divided into two general classes, "not filature" and "filature." The term "not filature" is applied to that reeled on a small scale in many different localities, and which as a result lacks uniformity, while "filature" is used to describe the product of the larger factories, which maintain standards of approximate uniformity.

Waste is commercially divided into two classes—No. 1 and No. 2—which correspond generally to the "big waste" and "second waste" already described. It is usually put up into bales of from 2 to 3 piculs ($266\frac{2}{3}$ to 400 lbs.).

11. Treatment of Wild Silk Cocoons.—Wild silk is much more difficult to unwind from the cocoons than that of the mulberry silkworm, and is also much darker in color. As the individual filaments are much coarser than those of mulberry silk the former, as a rule, have greater strength, but on reduction to a basis of equal diameters, the filaments of mulberry silk are somewhat stronger, and are much less difficult to dye and bleach.

The cocoons of tussah silk are usually boiled in an alkaline solution before reeling. The natives add the ashes of plantain leaves to water and boil the cocoons in this liquor for two to three hours, and then leave them to ferment for some hours before reeling. In some factories in Bengal, the cocoons with their stems cut off are tied up loosely in a cloth, which is weighted down with stones and boiled for half an hour in a liquor containing 3 parts of potassium carbonate dissolved in 80 parts of water, oil and sugar being sometimes added. The cocoons are afterward boiled for a few minutes in water containing a little glycerol. The silk is then reeled in the same way as mulberry silk. The glycerol keeps the cocoons moist while reeling, and it is not necessary to keep them in basins of water during this operation. Another method is to prepare a fine powder or paste from the chrysalides of the silk insects; and about 1 part by weight of this is mixed with 2 parts by weight of dry cocoons, and the mixture is tied up in a cloth, immersed in water and boiled for an hour. The mixture is next left to ferment for twelve hours, after which the reeling begins, the cocoons being allowed to rotate in basins of hot water. The reeled

silk, obtained by whatever process, must next be immersed in a warm acid solution, then washed in a bath of boiling soap or washing soda solution, and finally rinsed in boiling water, wrung out, dried, and baled. The object of the acid bath is to neutralise the lime and alkali which would lessen the brilliancy and elasticity of the fiber. The acid solution is prepared from tamarinds, using 1 part by weight of tamarinds to every 4 parts of silk. The tamarinds are washed and mixed with water, and the liquor is strained through a cloth. One man can reel about 260 tussah cocoons in a day, obtaining about $\frac{1}{2}$ lb. of silk. One difficulty in reeling tussah silk is to make the separate strands cohere in the reeled thread; in the case of mulberry silk the glue is only softened in the reeling basin and glues the strands together by hardening again.

Tussah (or tussur) silk, as well as other wild silks, is chiefly employed for making pile-fabrics, such as velvet, plush, and imitation sealskin.

12. Spider Silk.—Attention has recently been drawn to the possibility of obtaining silk from a species of spider chiefly found in Madagascar. The spider is known as *Nephila Madagascariensis*. The egg-receptacle is a silky cocoon about 1 in. in diameter and of a yellow color, but turning white after several months' exposure to the air. The female spider alone produces the silk and is about $2\frac{1}{2}$ ins. long. The silk is reeled off from the spider five or six times in the course of a month, after which it dies, having yielded about 4000 yds. The reeling is done by native girls; about one dozen spiders are locked in a frame in such a manner that on one side protrudes the abdomen, while on the other side the head, thorax, and legs are free. The ends of their webs are drawn out, collected into one thread, which is passed over a metal hook, and the reel is set in motion by a pedal. The extraction of the web does not apparently inconvenience the spider. The cost of the material is high, as 55,000 yds. of 19 strands thickness weighs only 386 grains, and 1 lb. of the silk is worth $40. At the Paris Exposition of 1900, a fabric was shown, 18 yds. long by 18 ins. wide, containing 100,000 yds of spun thread of 24 strands, the product of 25,000 spiders. It was golden yellow in color. Spinning spiders are also known in Paraguay, Venezuela, and other countries.

Spider silk under the microscope appears solid, almost completely transparent, of approximately circular cross-section and without any internal structure. The extraordinary fineness of the white threads is noticeable, the average diameter being only 6.9 microns; consequently they are the finest animal silk product, being finer even than the most delicate filaments of artificial silk. Spider silk is not surrounded by an enveloping substance like the sericine of ordinary silk. The density is about the same as that of ordinary silk—namely, 1.34. When immersed in water spider silk swells considerably and contracts in length. In its microchemical tests it is similar to true silk.

The threads spun by the *Nephila Madagascariensis* closely resembles ordinary silk in external appearance. Each spider produces about 150–600 meters of fiber. The silk has an orange-yellow color, which becomes intensified by alkalies and is destroyed by acids. It differs from ordinary silk principally in its small amount of silk-glue (or water-soluble substances). According to Fischer [1] spider silk gave the following products when hydrolysed with acid:

	Percent.
Glycocoll	25.13
d-alanine	23.40
l-leucine	1.76
Proline	3.68
l-tyrosine	8.20
d-glutaminic acid	11.70
Diamino acids	5.24
Ammonia	1.16
Fatty acids	0.59

Glutaminic acid, which is present in rather a large amount in spider silk, has not been found in ordinary silk. Spider silk, on ignition, gave 0.59 percent of ash.

13. Silk Statistics.—With the possible exception of China, for which no complete statistics are available, the United States is now the largest silk manufacturing country in the world.

The following tables indicating the extent of the silk manufacturing industry in the United States for the year 1919 have been taken from the U. S. Census Reports:

PRINCIPAL MATERIALS USED IN SILK INDUSTRY

Materials.	Quantity, Pounds.		Cost, Dollars.	
	1919.	1914.	1919.	1914.
Raw silk	25,890,728	23,374,700	206,222,609	86,416,857
Organzine, tram and hard crêpe twist	6,125,490	3,855,899	62,487,939	16,703,096
Spun silk	4,767,679	3,209,309	25,874,715	8,094,427
Frisons, pierced cocoons, noils and other waste	11,461,588	4,328,536	16,136,213	3,066,297
Artificial silk	3,039,257	1,902,974	15,885,564	3,440,154
Cotton yarns (not mercerised)	15,131,047	16,869,511	14,151,863	6,163,240
Mercerised cotton yarns	2,826,965	1,464,299	4,266,593	1,078,337
Woolen and worsted yarns	638,334	1,987,918	2,157,743	2,087,804
Mohair and other yarns	1,042,790	2,936,727	2,214,584	2,043,306

[1] *Zeit. physiol. Chem.*, 1907, p. 126.

The following table gives the value of the various manufactured products of the domestic silk industry:

PRODUCTS OF THE SILK INDUSTRY

	1919.	1914.
Total value	$688,502,534	$254,011,257
Broad Silks: Yards	310,132,060	216,033,696
Value	$391,735,902	$137,719,564
Velvets: Yards	16,150,689	16,318,135
Value	$20,950,239	$8,570,022
Plushes: Yards	5,860,427	9,114,992
Value	$21,601,280	$10,135,842
Upholstery and Tapestries: Yards	516,281	477,699
Value	$2,156,617	$840,126
Ribbons, value	$66,186,609	$38,201,293
All Silk, value	52,047,330	
Silk and Other Materials, value	14,139,279	
Laces, Nets, Veils, Veiling, etc., value	$5,825,359	$1,328,933
Embroideries, value	127,522	$33,500
Fringes and Gimps, value	3,026,560	1,025,188
Braids and Binding, value	13,218,284	3,073,648
Tailor's Trimmings, value	634,058	210,741
Military Trimmings, value	682,909	431,422
Machine Twist: Pounds	773,843	659,540
Value	$10,644,095	$4,036,807
Sewing and Embroidery Silk: Pounds	515,222	902,499
Value	$7,089,813	$5,644,806
Fringe and Floss Silks: Pounds	38,107	
Value	$500,571	
Organzine, for sale: Pounds	886,014	1,492,999
Value	$9,122,457	$6,325,291
Tram, for sale: Pounds	3,611,901	2,577,402
Value	$31,494,535	$9,698,637
Hard Crêpe Twist, for sale: Pounds	1,070,845	
Value	$12,011,137	
Spun Silk, for sale: Pounds	3,956,687	1,607,416
Value	$23,807,338	$4,577,058
Spun Silk, for sale, Singles: Pounds	1,764,028	
Value	$11,733,463	
Spun Silk, for sale, two or more ply: Pounds	2,192,609	
Value	$12,073,875	
Artificial Silk: Pounds	829,083	
Value	$5,423,242	
All other Products, value	$23,928,982	$13,757,772
Received for contract work	38,335,025	8,400,607

The total estimated production of raw silk in the world for the year 1914 was as follows:[1]

Italy	7,357,000 lbs.	
France	799,000 "	
Austria	655,000 "	
Spain	164,000 "	
Europe		8,975,000 lbs.
Levant		5,115,000 "
China, Shanghai	8,651,000 lbs.	
China, Canton	5,876,000 "	
Japan	25,132,000 "	
India	343,000 "	
Asia (exported)		40,002,000 lbs.
Total		54,092,000 "
Raw Tussah		3,307,000 "

[1] The filatures (silk reeling establishments) in Europe and the Levant for the year 1920 are given as follows:

	Basins.	Filatures.
Italy	58,620	1,039
France	16,000	161
Brussa	.....	50
Syria	.....	30
Turkey (all provinces)	.....	114
Greece	.....	22

In Italy the reeling of raw silk from the cocoon is done almost exclusively by girls, who receive about 28 cents per day of eleven hours; in Turkey the pay is about 30 piastres. In China and Japan the pay is even lower than this. As silk reeling has to be done by hand labor, and, owing to the fineness of the thread and the close inspection necessary, only a relatively small production of reeled silk can be obtained from each operative, it will readily be appreciated that this operation could not be conducted in either America or England on account of the much higher cost of any available labor. Even in Italy and France, since the advent of the war, labor costs of even girl silk reelers have much advanced, and it is becoming increasingly difficult to obtain a good supply of satisfactory labor. Silk reeling requires skill and a considerable period of apprenticeship, and a good silk reeler is to be considered as a skilled laborer. There is no doubt that the cost of silk reeling will be continually advancing even in Japan and China, though it will perhaps take many years before the labor in these countries will come up to anything approaching par with European countries. It seems rather certain therefore that sericulture in Italy and France, and even in the Levant, will show a tendency to decrease and that of China and Japan to increase in the next couple of decades. As the cost of reeling silk from the cocoons is one of the principal factors in the cost of raw silk, it also seems certain that the price of raw silk will continually tend to seek higher levels, and there is very little likelihood of its ever going back to the old pre-war figure. Another factor to be considered is the increasing production of artificial silk, which in many cases is capable of taking the place of real silk and at a much lower cost. While the price of real silk has every force acting to make it rise, the price of artificial silk, being almost entirely a mechanical operation, will tend to fall. We may expect, therefore, that artificial

The figures given for Asiatic silk are the exports, as the production of raw silk in China is not known. The domestic consumption of Japan is estimated as about 30 percent of the production, so the total production for Japan would be about 34,072,800 lbs. The domestic consumption of China is estimated as about 55 percent of the production, so the total production of China may be taken as about 41,604,000 lbs.

The production and exportation of raw silk has become one of the principal industries of Japan. In that country three silk crops are raised —in the spring, summer, and autumn. These form, respectively, about 50 to 55 percent, 5 to 10 percent, and 35 to 40 percent of the total annual production.

The following figures for the world's production of silk over a number of years are given by the *Board of Trade Journal*:

WORLD'S PRODUCTION OF SILK, 1876–1910

Period.	W. Europe.	S.E. Europe, Levant, etc.	Far East.	Total.
	Kilos.	Kilos.	Kilos.	Kilos.
1876–1880	2,475,000	637,000	5,740,000	8,854,000
1881–1885	3,630,000	700,000	5,108,000	9,438,000
1886–1890	4,340,000	738,000	6,522,000	11,600,000
1891–1895	5,518,000	1,107,000	8,670,000	15,295,000
1896–1900	5,220,000	1,552,000	10,281,000	17,053,000
1901–1905	5,312,000	2,304,000	11,476,000	19,092,000
1906–1910	5,459,000	2,636,000	14,917,000	23,012,000

For Persia, Turkestan, and the Far East the figures given are for exports only, and do not include what may have been used in domestic consumption in those countries.

During the World War, of course, the production of silk in Europe and the Levant fell off very greatly, and owing to the disturbed condition of these countries ever since the recovery in this industry has been very slow. There have been many efforts on the part of the various governments interested to re-establish sericulture on even a greater scale than ever before, but progress so far has been rather slow.

The following tables have been compiled by the Silk Association of America (1922):

silk will displace real silk in many of its uses, and the true fiber of the silkworm will be confined to the manufacture of those higher grade and more costly materials for which it is so eminently suited, and for which artificial silk would be a poor substitute.

RAW SILK PRODUCTION, INCLUDING TUSSAH SILK

Crops in Pounds.	1921–1922. Pounds.	1920–1921. Pounds.	1919–1920. Pounds.
Europe	7,628,000	8,058,000	4,927,000
Italy	7,066,000	7,330,000	4,045,000
France	430,000	551,000	397,000
Austria	.....	.....	331,000
Spain	132,000	177,000	154,000
Levant	1,213,000	1,654,000	2,293,000
Asia: Total quantity exported	48,740,000	35,138,500	51,860,000
China, Shanghai	6,555,000	6,518,500	10,225,000
China, Canton	5,578,000	4,210,000	7,093,000
Japan, Yokohama	36,376,000	24,300,000	34,222,000
India	231,000	110,000	320,000
Total, pounds	57,581,000	44,850,500	59,080,000
Tussah	1,856,000	1,650,000	1,960,000
Grand total, pounds	59,437,000	46,500,500	61,040,000

The production of raw silk in China [1] and India is unknown. The Japan crop is approximately 45,642,000 lbs. The export figures from Shanghai, China, exclude tussah silk. The world's production for 1913 (pre-war) was estimated at 60,104,000 lbs., so it may be seen that the war seriously interfered with the natural increase in silk production, as the figures for 1922 are practically the same as for 1913. The quantity of silk produced in western Europe is steadily decreasing. There have been recent attempts to introduce sericulture into the French African and Eastern Colonies, but satisfactory climatic conditions have not been attained.

[1] The silks of North China include those known as "steam filatures," which are reeled by European methods, and those known as "Tsatlees," which are reeled in a very primitive fashion without killing the chrysalides in the cocoons. The Tsatlee silk is therefore usually coarse and irregular. Chinese and Japanese silks are packed in *picul* bales of $133\frac{1}{3}$ lbs. Canton silk comes from the south of China and is generally reeled in the 14/16 denier size and is packed in bales of 80 *catties* (equivalent to $106\frac{2}{3}$ lbs.). Japanese silks are usually quoted in terms of *yen* per 100 *kin* (132.277 lbs.). The *momme* weight is 0.13228 oz. and this factor is often employed in calculations relating to Japanese silks.

Silk Products	1921–1922.	
	Pounds.	Value.
Raw Silk	48,178,964	$300,445,363
Waste Silk	9,097,339	6,717,210
Cocoons	161,044	120,310
Fabrics in the Piece: France	264,071	2,119,032
Italy	51,720	377,737
Switzerland	75,413	556,923
China	484,456	1,359,889
Japan	2,171,849	13,495,068
Other Countries	92,284	648,032
Total	3,139,793	$18,556,681
Ribbons: not over 12 ins. in width—yards	8,366,852	$451,160
Laces and Embroideries: France	.....	$4,369,784
United Kingdom	.....	577,290
Japan	.....	199,182
Other Countries	.....	460,078
Total	.....	$5,606,334
Velvets, Plushes and Other Pile Fabrics	387,490	$2,603,813
Spun Silk or Schappe Silk: France	779,008	2,178,214
Italy	137,131	460,947
Switzerland	470,274	1,438,415
United Kingdom	92,333	205,220
Other Countries	16,192	26,735
Total	1,494,938	$4,309,531
Wearing Apparel: France	.....	$3,228,854
Switzerland	.....	121,415
United Kingdom	.....	492,132
Japan	.....	1,040,222
Other Countries	.....	732,150
Total	.....	$5,614,773
Bandings, Beltings, Bindings, etc	.....	$253,945
All Other Manufactures	.....	2,634,096
Total Dutiable Silk	.....	$40,030,333
Bolting Cloth	.....	307,511
Total Silk Manufactures	.....	$40,337,844
Artificial Silk Yarns	2,912,960	$5,091,940
Artificial Silk, all other	.....	2,026,082
Total Artificial Silk	.....	$7,118,022

The table on page 268 gives the silk products, other than raw silk, imported into the United States during the year 1921–22 as reported by the Department of Commerce.

IMPORTS OF RAW SILK MATERIALS INTO THE UNITED STATES

Imports.	1921–1922.
Raw Silk, including Tussahs and Doppioni, bales	354,363
Raw Silk, including Tussahs and Doppioni, pounds	48,178,964
Raw Silk, invoice value, dollars	$300,445,363
Spun Silk, pounds	1,494,938
Spun Silk, invoice value, dollars	$4,309,531
Waste Silk, pounds	9,097,339
Waste Silk, invoice value, dollars	$6,717,210

THE CLASSIFICATION OF THE RECEIPTS OF RAW SILK IN THE UNITED STATES

Shipping Bales.	1921–1922.		
	Bales.	Pounds.	Value.
Europeans	9,103	2,260,177	$ 12,538,596
Japans	282,450	38,590,110	249,108,057
Cantons	40,559	4,341,995	23,331,168
Chinas	16,810	2,249,477	13,190,413
Tussahs	5,441	737,205	2,277,129
Totals	354,363	48,178,964	$300,445,363

CHAPTER X

PHYSICAL PROPERTIES OF SILK

1. The Microscopy of the Silk Fiber.—Under the microscope raw silk exhibits an appearance which readily distinguishes it from other textile fibers. The fiber of fibroine when purified from adhering sericine is seen as a smooth structureless filament, very regular in diameter and very transparent. Occasionally constrictions occur in the fiber as well as swellings or lumps. The two brins in the bave of raw silk give beautiful colors with polarised light when examined microscopically. The sericine coating, however, appears to have no such action. The latter, being hard and brittle, on bending develops transverse cracks which are very apparent under the microscope.

The fiber of *Bombyx mori* is only rarely striated longitudinally, and when such striations do appear they always run parallel to the axis of the fiber. When treated with dilute chromic acid very fine striations are caused to appear. Wild silks often show fibers which are twisted on their axes, and the layer of gum is usually more or less granular. *Antheræa mylitta* shows rather frequent oblique striations, and does not exhibit much play of color with polarised light. This latter characteristic is also true of *Antheræa yama-mai*. The other silks give nice colors with polarised light. Silk fibers are colored a deep red with alloxanthin; fuchsine also gives a red color. On treatment with sugar and sulfuric acid, silk is first colored a rose-red and then dissolves; hydrochloric acid gives a violet color and then dissolves the fiber. Iodine colors the fibers yellow to reddish brown.

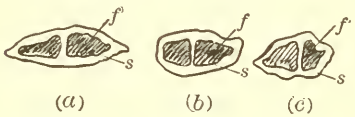


FIG. 139.—Cross-sections of Silk Fiber. (×500.) *a*, From inner part of cocoon; *b*, from middle layers; *c*, from outer part; *f*, fiber of fibroine; *s*, layer of sericine. (Micrograph by author.)

Carded silk, which has been worked up from imperfect cocoons, etc., can usually be recognised under the microscope by the irregular and torn appearance of its external layer of gum.

The inner layers of the cocoon consist of a yellow parchmentlike skin, and when examined under the microscope exhibit a matrix of sericine, in which numerous double fibers are imbedded, usually very much flattened

in cross-section (Fig. 139, *a*). These inner layers, of course, are not capable of being reeled with the rest of the cocoon, and are used for waste silk. The cross-sections of the fibers from the middle portion of the cocoon, constituting the reeled silk are much more rounded in form and are surrounded with a thinner layer of sericine (Fig. 139, *b*). The fibers of the outer part of the cocoon, also utilised for waste silk, exhibit a rather irregular cross-section (Fig. 139, *c*).

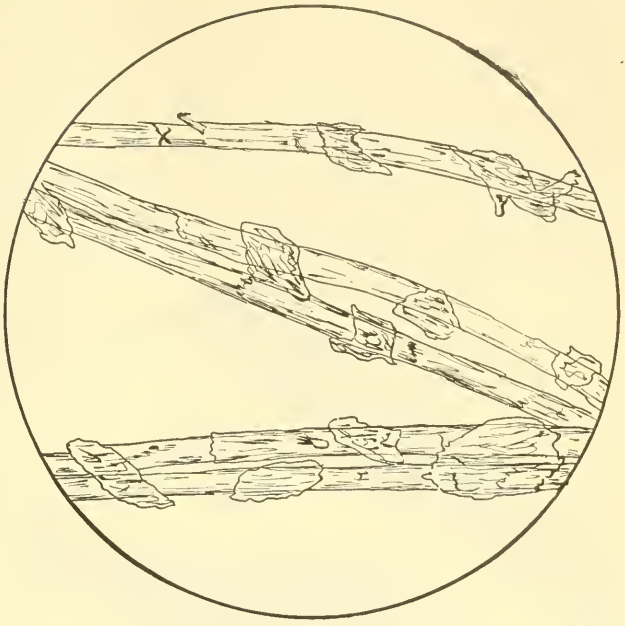


FIG. 140.—Appearance of Raw Silk (×500) under the Microscope, Showing the Double Cocoon Filament and the Irregular Shreds of Silk-glue. (Micrograph by author.)

When raw silk is examined under the microscope it will be seen that the appearance is by no means regular, owing to the broken and torn surface of sericine which surrounds the fiber (Fig. 140). Frequently the two filaments of fibroine are distinctly separated from one another for considerable distances, the intervening space being filled in with sericine. Occasionally the layer of sericine is seen to be entirely absent, having been removed by breaking or rubbing off. The sericine layer also shows frequent traverse fissures, which are merely cracks caused by the breaking of the sericine in the bending or twisting of the fiber. Creases and folds in the sericine, as well as irregular lumps, are also of frequent occurrence. All of these markings are in nowise structural, and only occur in the sericine layer. At times the

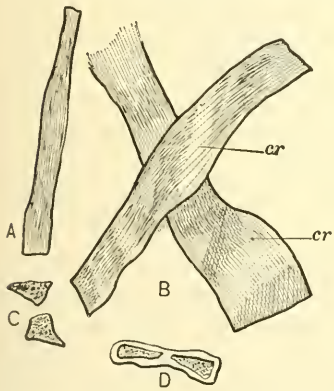


FIG. 141.—Wild Silk. (×250.) *A*, View of narrow side; *B*, view of broad side; *C*, cross-section; *D*, cross-section of double fiber; *cr*, cross-marks on fiber. (Micrograph by author.)

fibroine fiber exhibits structural changes in places, such as attenuations; but these only occur in defective and unhealthy silk, and give rise to weak places. These are caused by the fibroine not being secreted by the gland with sufficient rapidity when the fiber is being spun by the worm.

The microscopic appearance of the wild silks is very different from that of the *Bombyx mori*. The fibers are very broad and thick, and in cross-section are very flat, and often triangular in outline. Longitudinally they show very distinct striations and peculiar flattened markings, usually running obliquely across the fiber, and in which the striations become more or less obliterated. These cross-markings are caused by the overlapping of one fiber on another before the substance of the fiber had completely hardened, in consequence of which these places are more or less flattened out (Fig. 141). The striated appearance of wild silk is evidence that structurally the fiber is composed of minute filaments; in fact the latter may readily be isolated by maceration in cold chromic acid (Fig. 142). According to Höhnel these structural elements are only 0.3 to 1.5 microns in diameter; they run parallel to each other through the fiber, and are rather more dense at the outer portion of the fiber than in the inner part (Fig. 143). Besides the fine striations on the fibers of wild silk caused by their structural filaments, there are also to be noticed a number of irregularly occurring coarser striations. These latter appear to be due to air-canals, or spaces between the filaments of the fiber.

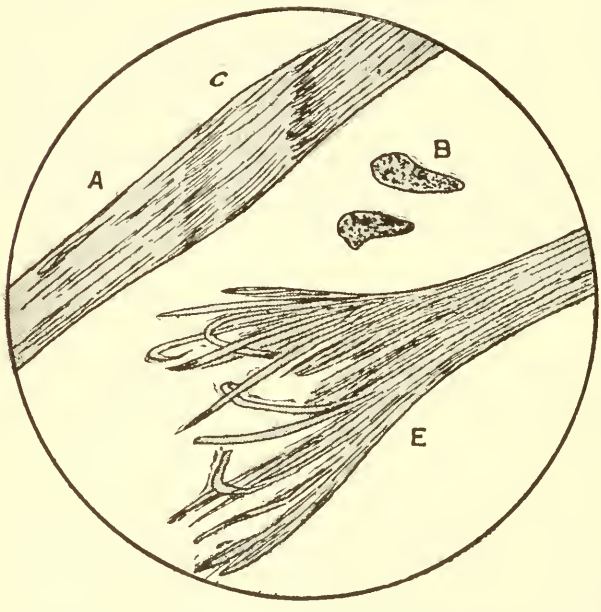


Fig. 142.—Tussah Silk. (×400.) *A*, View of broad side; *C*, cross-mark; *B*, cross-sections; *E*, torn end showing fibrillæ. (Micrograph by author.)

Höhnel is of the opinion that there is really no difference in kind between the structure of wild silk and that of cultivated silk; that is to say, the fibroine fiber of the latter is also composed of structural filaments, only they fuse into one another in a more homogeneous manner on emerging

from the fibroine glands, thus rendering it more difficult to recognise them superficially. This view is upheld somewhat by the fact that a slight striated appearance may be noticed when the silk fiber is macerated in chromic acid solution. This apparent structure of the silk fiber, however, may also be due to another cause. If a plastic glutinous mass (such as melted glue, for instance) be pulled out into the form of a thread and allowed to harden, it will be found to exhibit the same striated structure as the silk fiber; and this structure will be more apparent if the thread is pulled out and hardened more rapidly. The liquid fibroine in the glands

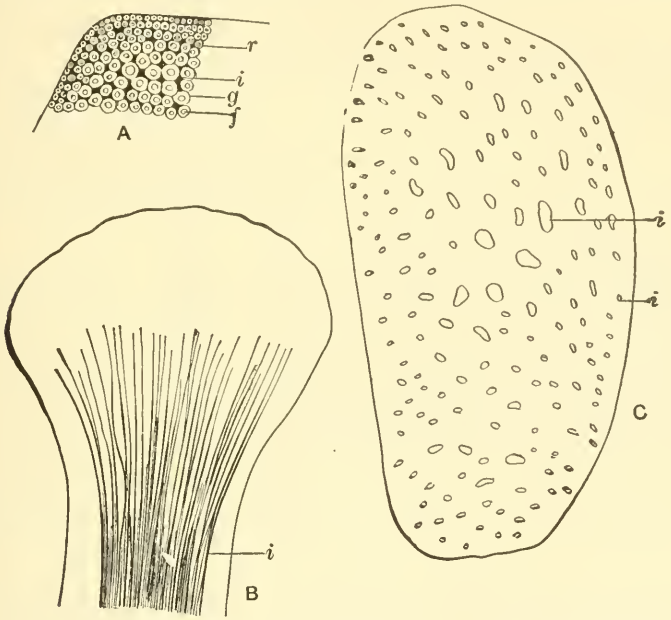


FIG. 143.—Cross-section of Wild Silk. *A*, diagrammatic drawing of section; *i*, air-space; *g*, ground matrix; *f*, fibrillæ; *r*, marginal layer; *B*, end of fiber of tussah silk swollen in sulfuric acid; *C*, cross-section of fiber of tussah silk swollen in sulfuric acid. (After Höhnel.)

of the worm is a plastic glutinous mass analogous to melted glue, and is pulled out into the form of a thread by the action of the worm in winding its cocoon; hence it would be natural to expect a striated structure similar to that observed in the thread of glue. Thus, it is possible to account satisfactorily for the structure of the silk fiber in a perfectly natural manner without having recourse to a very doubtful organic process in the formation of the fiber, such as is supposed to be the case by Höhnel.

2. Physical Properties of Silk; Hygroscopic Nature.—Silk is quite hygroscopic, and under favorable circumstances will absorb as much as

30 percent of its weight of moisture and still appear dry. It is therefore customary to determine the amount of moisture in each lot at the time of sale. This is called **conditioning,** and is usually carried out in official laboratories. The amount of "regain" which is officially permitted is 11 percent; this would be equivalent to 9.91 percent of moisture in the silk. Boiled-off silk appears to contain somewhat less moisture than raw silk, the silk gum having a greater attraction, or power of absorbing water, than the fiber proper. The amount of moisture in boiled-off silk is usually regarded as about 8.45 percent, which would correspond to a regain of 9.25 percent. The Milan Commission (1906) adopted a temperature of 140° C. for the conditioning of silk, as it is found to be difficult to completely dry the fiber at 110°–120° C.

3. Electrical Properties.—Being a bad conductor of electricity, silk is readily electrified by friction, which circumstance at times renders it difficult to handle in the manufacturing process. The trouble can be overcome to a great extent by keeping the atmosphere moist. Owing to its poor conductivity silk is largely used for covering insulated wires in electrical apparatus.

4. Luster.—The most striking physical property of silk, perhaps, is its high luster. The luster only appears after the silk has been scoured and the silk-gum removed. The luster of silk is affected more or less by the various operations of dyeing and mordanting, and especially when the silk is heavily weighted. After dyeing, especially in the skein form, silk usually undergoes what is termed a lustering operation, which consists generally in stretching the hanks strongly by twisting, and simultaneously steaming under pressure for a few minutes. This process seems to bring back to a considerable extent the luster of the dyed silk. Lustering, or "brightening," may also be accomplished by steeping the skeins of silk in a solution of dilute acid, such as acetic or tartaric, squeezing, and drying without washing. The luster is also considerably affected by the method of dyeing and the chemicals employed in the dye-bath; it has been found that the addition of boiled-off liquor (the soap solution of sericine obtained in the degumming of raw silk) to the dye-bath has the result of preserving the luster of the dyed silk better than anything else, and in consequence boiled-off liquor is nearly always employed as the assistant in dyeing in preference to glaubersalt or common salt.

The lustering of silk in the woven fabric is brought about in a variety of ways and leads us into the many processes of silk finishing. One process which is very extensively employed is that which results in what is known as a "moiré," or "watered," finish.

This finish is produced by a mechanical process which transforms the appearance of the fabric. The fabrics best suited to receive the moiré finish are those in which the weave is most distinct. The process is chiefly

used for finishing silk fabrics such as *poult de soie, gros de Tours* and fabrics made with silk warp and cotton or wool filling, that is, with a fine, closely set warp and a fairly coarse filling. This finish gives to the cloth a marblelike effect which varies in form and aspect according to the direction from which it is examined. The operation flattens the threads and as a result of the crushing of the filling at certain points variable lines and shades are produced arising from the combination of surfaces reflecting light at different angles.

The discovery of this finish was made by the Chinese who enjoyed a monopoly of it for a long time. The English were the only ones to employ it in Europe previous to 1754.

There are two processes of moiré finish: *moiré antique,* and *moiré ronde.* Badger introduced into France the moiré antique finish which is still called English, while the other finish is called French.

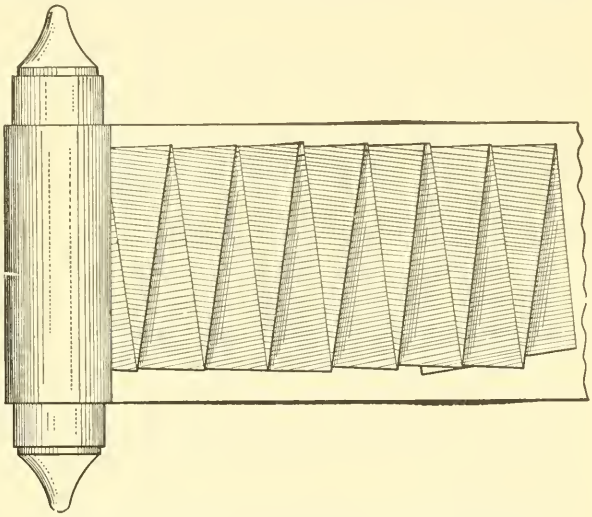


Fig. 144.—Method of Folding Silk for Moiré Finish.

For the moiré antique finish the cloth is first folded so as to join the selvages, which are then fastened by sewing at intervals of 10 to 15 ins., the face of the cloth being inside. If one of the selvages is longer than the other it is slackened before sewing the two together in order that the filling may be held in its normal position. The edge of the fabric is then cut obliquely with scissors. The finish will be imperfect if the selvages stretch more than the body of the cloth. After doubling, the piece is folded in 2-ft. lengths, one fold on top of the other. The piece is now placed on a strong linen fabric in such a way that the folds form an angle of 45°, as shown in the figure (Fig. 144). In other words the folds instead of being superimposed vertically are arranged so that the ends are drawn in on one side and project on the other. In this way the two sides of the folds form a gradual slant terminating in a single fold. This special method of folding is called " dossage oblique." The fabric thus arranged is wound on a roller from 6 to 9 ins. in diameter and is then covered with several thicknesses of strong cloth, which is tied with cords at the ends. The roll is then carried to the mangle.

In the moiré effect by calender finish, a hydraulic calender capable of giving pressures of over 100,000 lbs. per square inch is used and the calender rolls are heated. In one process the piece is first folded and the selvages sewed. When two filling threads come directly over one another and pass through the calender the increased thickness thus obtained causes a crushing of the filling threads. On the other hand, the filling threads retain their round form on the other parts of the fabric. There are quite a variety of moiré finishes depending on the manner of passing the goods through the calender. Also, different effects may be obtained by using one fabric at a time, or by using two pieces of the same cloth, or by using two different fabrics. Of later years the use of engraved rollers has been introduced and in this manner all kinds of moiré patterns and effects may be obtained. In all forms of moiré finish the luster effect is produced by the fine lines or striations made by the great pressure on the threads. This character of surface acts in much the same manner as a diffraction grating and diffracts the reflected light. Also, the smooth, flat, small surfaces act like tiny mirrors in reflecting the light more perfectly. The wavelike form or pattern of the luster gives it the well-known name of "watered" silk.

5. Tensile Strength and Elasticity.—Silk is also distinguished by its great strength. It is said that its tensile strength is comparable to that of an iron wire of equal diameter.[1] The silk fiber is also very elastic, stretching 15 to 20 percent of its original length in the dry state before breaking. Degummed or boiled-off silk is somewhat lower in strength and elasticity than raw silk, the removal of the silk-gum apparently causing a decrease of 30 percent in the tensile strength and 45 percent in the elasticity. The weighting of silk also causes a decrease in its strength and elasticity.

The table on page 277 gives the diameter, elasticity, and tensile strength of the cocoon-thread of the chief varieties of silk.[2]

6. Density.—The density of silk in the raw state is 1.30 to 1.37, while boiled-off silk has a density of 1.25. Silk, therefore, is somewhat lighter than cotton, linen or artificial silk, all of which, being cellulose fibers, have a density of 1.50. Silk is also slightly lighter than wool and hair fibers which have a density of 1.33 to 1.35. The figures given here for the density of silk apply, of course, to the pure unweighted fiber. In weighted silks the density increases with the degree of weighting, as the metallic weighting materials all have a much higher relative density than the fiber itself.

[1] The breaking strain of raw silk is equivalent to about 64,000 lbs. per square inch, or nearly one-third that of the best iron wire.

[2] Wardle, *Jour. Soc. Arts*, vol. 33, p. 671.

Name of Silk.	Country.	Diameter, Inches.		Elasticity, Inches in 1 Foot.		Tensile Strength, Drams.		Size of Cocoon, Inches.
		Outer Fibers.	Inner Fibers.	Outer Fibers.	Inner Fibers.	Outer Fibers.	Inner Fibers.	
Bombyx mori.....	China	0.00052	0.00071	1.3	1.9	1.6	2.6	1.1×0.5
Bombyx mori.....	Italy	0.00053	0.00068	1.2	1.9	1.9	2.6	1.2×0.6
Bombyx mori.....	Japan	0.00057	0.00069	1.2	1.4	2.0	3.1	1.1×0.6
Bombyx fortunatus.	Bengal	0.00045	0.00051	1.8	2.3	1.6	2.8	1.2×0.5
Bombyx textor.....	India	0.00042	0.00047	1.5	1.9	1.4	2.6	1.2×1.5
Antheræa mylitta...	India	0.00161	0.00172	1.9	2.7	6.6	7.8	1.5×0.8
Attacus ricini.....	India	0.00085	0.00093	1.7	2.0	1.5	3.0	1.5×0.8
Attacus cynthia....	India	0.00083	0.00097	2.6	2.9	2.4	3.5	1.8×0.8
Antheræa assama...	India	0.00128	0.00125	2.4	2.9	2.8	4.8	1.8×1.0
Attacus selene.....	India	0.00100	0.00109	2.0	2.8	2.4	4.0	3.0×1.2
Attacus atlas.....	India	0.00102	0.00111	1.9	2.8	2.1	4.1	3.5×0.8
Antheræa yama-mai.	Japan	0.00088	0.00096	2.0	4.0	6.8	7.5	1.5×0.8
Cricula trifenestrata	India	.....	0.00120	....	....	....	....	2.0×0.8
Antheræa pernyi....	China	0.00118	0.00138	2.0	2.7	3.2	5.8	1.6×0.8

7. Scroop.—Another property of silk, and one which is peculiar to this fiber, is what is termed its scroop; this refers to the crackling sound emitted when the fiber is squeezed or pressed. To this property is due the well-known rustle of silken fabrics. The scroop of silk does not appear to be an inherent property of the fiber itself, but is acquired when the silk is worked in a bath of dilute acid (acetic or tartaric) and dried without washing. A satisfactory explanation to account for the scroop has not yet been given; it is probably due to the acid hardening the surface of the fiber. Mercerised cotton can also be given a somewhat similar scroop by such a treatment with dilute acetic acid. Wool, under certain conditions of treatment, in some degree can also be given this silk-like scroop, as, for instance, when it is treated with chloride of lime solutions or with strong caustic alkalies. In many manufactured articles scroop is considered as a desirable property, and by some is supposed to indicate a high quality of silk; but this is not the case, as the scroop, crunch or rustle of silk is purely an acquired property added by artificial treatment, and it does not enhance the real value and quality of the silk.

8. Silk Reeling.—The silk fiber, as it appears in trade for use in the manufacture of textiles, is obtained by unreeling the cocoon. After the cocoons have been spun by the silkworms they are heated in an oven for several hours at a temperature of from 60° to 70° C., for the purpose of killing the pupa or chrysalis contained within, before the latter shall

have developed sufficiently to begin cutting its way through the envelope and thus destroy the continuity of the cocoon-thread. Another method of operation is to steam the cocoons; this requires only a few minutes to kill the pupa, and is said to be preferable to the oven-heating, as it causes less damage to the fiber, and at the same time considerably softens the silk-glue, thus rendering the subsequent process easier.

After the killing of the worms is accomplished, the cocoons are sorted into several grades, according to size, color, extent of damage, etc., after which they are ready for reeling. This is entirely a mechanical process requiring much skill. The cocoons are soaked in warm water until the silk-glue is softened; the operator seizes the loose ends of several fibers together on a small brush and passes them through the porcelain guides

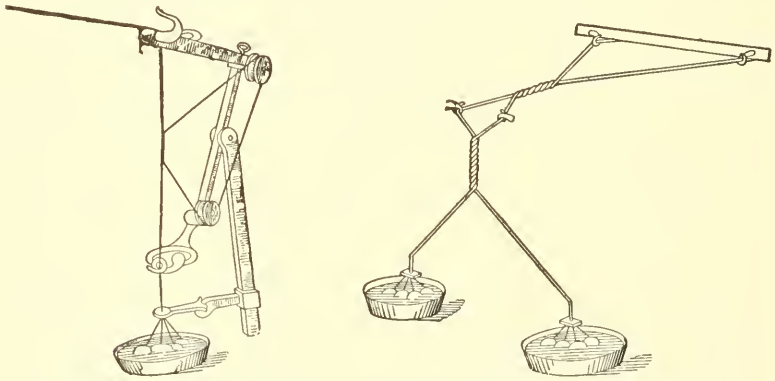


Fig. 145.—Showing Methods of Reeling the Silk Fiber from the Cocoon.

of a reel, where they are twisted together to form threads of sufficient size for weaving. Two threads are formed simultaneously on each reel, and are made to cross and rub against each other to remove twists in the fiber (Fig. 145), and also to rub the softened silk-glue coverings together in order that the fibers may become firmly cemented and form a uniform thread. It is customary in most filatures to reel the thread of five cocoons together into a single yarn, giving a raw silk of 13/15 denier.

The product so obtained is termed **raw silk** or **grège. Singles** is the name applied to all raw silk composed of a number of silk filaments twisted together during the reeling of the silk.

Floss silk, which is used for making **spun silk,** is the term applied to the waste resulting from short and tangled fibers from the exterior of the cocoon, and from those cocoons which have been broken by the moth in escaping. In the practical reeling of silk three cocoons (six filaments) make about the finest size of silk that can be commercially employed; the great bulk of skein silk, however, is reeled from about five cocoons

(ten filaments), this making the size known as 13/15 deniers. The majority of the raw silk of commerce is now reeled into skeins of standard circumference and of a convenient weight, and the skeins are generally reeled with a quick traverse (Grant reel) so that a broken end cannot get lost in the skein. Reeled silk varies much in character, cleanliness, strength, elasticity, and other qualities. Silk reeled in summer is also generally superior to spring reeling of the same grade. Raw silk in the ungummed state can be employed directly in only a limited number of fabrics, as in the warps of piece-dyed cotton-back satins. Cultivated raw silks have either a white or yellow color; generally speaking, all the China, Japan and Levantine silks are white, and the European silks are yellow.

Yarns made from spun silk differ considerably from reeled silk in being fuller, bulkier, and softer, they have less luster than reeled yarns, are not so uniform, and cannot be spun to such fine counts. Spun silk yarns are extensively used for the production of velvets and plushes, for striping and checking in woolen and worsted fabrics, for silk handkerchiefs, hosiery, laces, etc. Combination yarns are also largely made by twisting a spun silk thread around a woolen, worsted, or cotton thread. Spun silk yarns are also extensively employed as a warp with woolen, worsted, or cotton filling for the production of umbrella cloth, scarfs, etc.

Raw silk is classified into two grades: (*a*) *Organzine* silk, which is made from the best-selected cocoons, and is chiefly used for warps on account of its greater strength; and (*b*) *Tram* silk, which is made from the poorer quality cocoons, and is mostly employed for filling.

Tram silk is the union of two, three, or more singles, only slightly twisted together, and is known as 2-thread, 3-thread, etc., tram, according to the number of singles used in the thread. Tram, as a rule, is used boiled-off, and only rarely in the gum, being degummed before dyeing in the hank. Organzine silk is the union of a 2-thread tram yarn with a large number of turns per inch of twist.

Organzine silk is made for warp threads, and has to undergo the processes of winding, warping, drawing or twisting, and weaving; in the loom it is subjected to heavy tension and has to withstand the chafing action of harness, reed, and shuttle, therefore the thread must be clean, smooth, well-knit and homogeneous. To make organzine it is customary to twist the raw silk threads together with 16 turns to the inch. Two or more of these threads are then doubled together and twisted 12 to 14 turns per inch in the reverse direction. In twisting organzine silk under ordinary conditions it is fair to allow from 4 to 5 percent for loss in length of the thread owing to the take-up or shortening in the twisting of the threads. For hard-twist silks this take-up is much more, being about 10 percent for 45 turns and 20 percent for 70 turns per inch.

Tram silk is used for the filling or weft and is not subjected to the friction of organzine warp threads; it would be undesirable to twist it much, as the woven goods would then feel thin and sheer and not have the full and lofty handle required. The single thread, therefore, is given no twist at all; three to six of these threads are doubled together and a twist of $2\frac{1}{2}$ to $3\frac{1}{2}$ turns per inch put in, this being required to hold the thread together in the dyeing and weaving, while at the same time it leaves the silk full and open, so that it fills the cloth properly.

Some silk, such as that used for chiffons, is twisted very hard, up to 80 turns per inch in the single, and is used in that form for both warp and filling.

9. Silk Throwing.—Before raw silk enters into manufacture it undergoes a process known as throwing. This is a mechanical operation in which the raw silk is first soaked in an oil or soap emulsion to soften up the fiber, without, however, dissolving the silk-glue. The silk is then reeled from the raw skeins so that several fibers are brought together, with more or less twist, into a yarn of any desired size. The "throwster," in other words, simply converts the raw silk yarn into a yarn of proper size for manufacturing, or by regulating the twist produces various qualities of silk thread for the several purposes required for the weaving or knitting of various kinds of fabrics. The term "throwing" is apparently derived from an Anglo-Saxon word "thraw," meaning to whirl or spin, and the word in this connection means to spin or twist the silk.

Silk throwing requires special skill and knowledge together with considerable plant and expensive machinery, and consequently it has developed into a separate and distinct business. The usual commercial practice is for the manufacturer to buy his raw silk on contract from the silk importer; it is then shipped to the throwster, and the latter in turn, after twisting as required, sends it to the dyer and weighter, who then sends it back to the manufacturer. It is only the largest silk manufacturers who combine in one mill the separate plants for throwing, dyeing, weighting and manufacturing.[1]

10. Classification of Silk Yarns.—According to the composition and twist of the threads, silk is classified into the following:

1. *Organzine* (*warp* or *Orsey* silk); from 3 to 8 cocoon threads are lightly twisted together with a right-hand twist, so that there are from 60 to 80 turns per centimeter, and 2 to 3 such threads are twisted together left-handed to form double or threefold organzine.

2. *Tram* or *weft* silk; characterised by a much lower degree of twist; the individual

[1] Current prices for throwing (1910) have been about 65 cents per pound for 2-thread 13/15 denier organzine, with 5 cents more for 12/14 and 5 cents less for 14/16 size. For tram silk about 35 cents per pound for 4-, 5-, or 6-thread, $37\frac{1}{2}$ cents per pound for 3-thread and 40 cents for 2-thread.

threads consisting of 3 to 12 cocoon threads undergo no preliminary twist, and 2 or 3 of these are united by loose twisting, so that the thread is softer and flatter than organzine.

3. *Marabout* silk; used for making crêpe, 2 to 3 threads being united without any preliminary twisting, then dyed without scouring and strongly twisted; a hard twist and stiffness are characteristic of this silk.

4. *"Soie Ondee;"* prepared by doubling a coarse and a fine thread; it is mostly used for making gauze, and gives a moiré or watered appearance.

5. *Cordonnet;* 4 to 8 twisted threads are combined by a loose left twist, and 3 of the threads thus formed are united by a right-hand twist; this silk is mostly used for selvages, braiding, crocheting, knitting, etc.

6. *Sewing* silk; made from raw silk of 3 to 24 cocoon threads, 2, 4, or 6 of which are united by twisting.

7. *Embroidery* silk; consists of a number of simple untwisted threads united by a slight twisting.

8. *Poil* or *single* silk; a raw silk thread formed by twisting 8 to 10 cocoon threads and employed for making gold and silver tinsel.

Floss or *waste silk* cannot be reeled, so the cocoon-threads are scoured in a solution of soda and soap, and afterwards combed and carded in special machines. There are two ways in which waste silk may be degummed for spinning: it may either be *boiled-off* or *chapped.* The former is usually adopted where all the gum is to be removed, and is carried out by tying the silk up in bags and boiling in a soap solution. In the second method the gum is loosened by a process of fermentation and only a portion of the gum is removed according to requirements. The process is carried to such perfection that as much as 15 percent or as little as 2 percent of the gum may be removed. In chapping, the waste silk is piled in a heap in a damp, warm place, and kept constantly moist; the gum soon begins to ferment and soften; by continual turning of the pile all portions of the heap are properly softened, but the process takes several days. Another process is to place the silk in cages and immerse in water for several days. The better quality and longer fiber of waste silk is worked up into what is known as *florette* silk, while the shorter fibers are carded and spun into *bourette* silk. Floss silk is also known as *chappe* or *échappe* silk. *Silk wadding* is produced from the waste left after bourette spinning.

11. Tests for Classification of Raw Silk.—The Silk Association of America has formulated the following standard tests for the classification of raw silk:

Article 1

Section 1.—These specifications for standard tests for raw silk are promulgated by the Silk Association of America for the purpose of standardising the official methods of testing silk in the United States in order to facilitate the transactions between buyers and sellers of silk, and to furnish the producers of raw silk on the primary markets accurate information upon the methods by which the characteristics of their products are to be determined by the American consumers. While the test methods

herein described constitute the standard tests as required in the rules and regulations governing transactions on raw silk, they are not to be construed as waiving the right in individual cases to make any or all of them in any other manner or to make such other tests as may be desired. They shall apply and govern as the methods to be used for official tests by the United States Testing Co., Inc., relating to contracts under the rules and regulations of the Silk Association of America and in other cases where no special or specific methods are agreed upon and are contained in the sales contracts.

Section 2. Definitions.—Raw silk is the single thread as reeled from cocoons, and is understood to be a continuous thread from beginning to end of the skein. The skeins in general conform in weight, circumference and lacing to the specifications for the American standard skein as issued and approved by the Silk Association of America. *Standard Condition.*—Where the expression "standard condition" is used in these specifications, it shall be understood to mean the condition of the silk when it contains 11 percent of its dry weight of moisture. *Standard Atmosphere.*—The expression "standard atmosphere" shall be understood to mean the condition of the air such that silk placed in it will within a reasonable period assume and retain a standard condition.[1]

Section 3. Sampling.—It is important in testing by means of samples drawn from the merchandise that the samples should be so selected as to be representative of the merchandise and that a sufficient proportion of the lot should be sampled to be representative of the entire lot to which the tests are to apply. The amount of sample and the number of samples herein specified are understood to be the minimum which can be considered as representative and which shall constitute an official sample in size and distribution. (*a*) *Sample for Test.*—The sample for a test shall consist of at least ten average original skeins, selected at random from different parts of a bale, not more than one skein to be drawn from any one book or bundle, and only skeins from a single bale to be included in any single test. Test samples for two or more different kinds of tests may be taken from the original ten skeins. (*b*) *Sample from Lot.*—If the results of tests are to represent and be applied to a lot, at least two tests must be made upon every five bales of the lot, one from each of two bales selected at random.

Article 2.—Winding Test

Section 1. Object.—The winding test is intended to show the manner in which the raw silk thread will pass through the winding operation.

Section 2. Sample.—The sample for the test and the sampling of the lot is as specified in Article 1, Section 3. Only original, intact skeins drawn fresh from the bale shall be used.

Section 3. Apparatus.—The winding frame upon which the test is made shall run at a uniform speed and be capable of adjustment to the following average thread speed, 120, 150, 180 yards per minute. *Standard Bobbin.*—To insure a uniform tension and speed the bobbin should have the following dimensions:

Diameter of head	50 mm. (2 inches)
Diameter of drum	46 mm. ($1\frac{7}{8}$ inches)
Length between heads	75 mm. (3 inches)

[1] A relative humidity of 65 percent at a temperature between 65° F. and 70° F. produces an approximate standard atmosphere. If the temperature rises above 70° F. the relative humidity must also increase to maintain the regain at 11 percent.

The bobbins should be constructed so as to be light, well balanced, and smooth, and should revolve smoothly without jumping. *Swifts.*—The swifts (tavelle) used in the test should be self-centering, geared-hub pin swifts without weights or twelve stick pin-hub swifts without weights.

Section 4. Skeins.—The sample skeins shall be put on the swifts with care to insure that each skein is in good condition. A record should be made of the degree of gum spots if any are present. Five skeins shall be wound from the top and five from the bottom. *Speed of Winding.*—The average thread speed of winding shall be adjusted according to the average size of the raw silk and shall be regulated as nearly as possible to the following speeds:

		Of 59″ Skein.
Below 13 denier	120 yards per minute =	73 R.P.M.
13 denier to 17 denier	150 yards per minute =	92 R.P.M.
Above 17 denier	180 yards per minute =	110 R.P.M.

The maximum thread speed of winding at the completion of the test shall not exceed the following:

		Of 59″ Skein.
Below 13 denier	140 yards per minute =	85 R.P.M.
13 to 17 denier	170 yards per minute =	104 R.P.M.
Above 17 denier	200 yards per minute =	122 R.P.M.

Winding.—During the winding test, the winding laboratory shall be maintained at as nearly a standard atmosphere as possible. *First Period.*—The skeins should be wound onto spare bobbins for fifteen (15) minutes. They should then be inspected to determine if any are in bad condition due to damage, mishandling or improper putting on. If any skeins are found to be in bad condition due to causes other than poor reeling, they shall, provided they do not exceed two in number, be omitted from the test, which shall be completed on the remaining skeins. If they do not exceed two in number, additional samples shall be drawn to replace the damaged ones. *Second Period.*—The spare bobbins shall then be replaced by standard bobbins and the winding continued until the standard bobbin for each skein is filled flush with the heads, care being taken to insure proper traverse to wind a smooth, compact bobbin.[1]

Section 8. Records. First Period.—A separate record shall be kept of the number of breaks occurring in the first fifteen minutes and special note made of excessive breaks in any particular skeins, stating the cause. *Second Period.*—After the inspection of the skeins, a record shall be kept of the breaks, and special attention given to any skeins showing an excessive number of breaks. *Weighing.*—When the bobbins are filled the raw silk will be re-reeled without waste into skeins, placed for at least two hours in a space maintained at a standard atmosphere so that they will regain moisture to the standard condition. They will then be weighed in grams, and the number of breaks per 100 grams calculated by proportion. The breaks per 100 grams may be converted into approximate breaks per pound by multiplying by 4.5.

Section 10. Rating in Percentage.—The winding may be expressed in percentage by assuming one break per 100 grams as 1 per cent and subtracting the number of breaks from 100 percent.

[1] The second period should require about one hour for a 14 denier raw silk and yield about 10,000 yards from each skein, or 100,000 yards (100 grams) for the test. Other sizes will require proportionately other yardages to fill the standard bobbins.

Article 3.—Sizing Test (450 meter)

Section 1. Object.—The sizing test is intended to determine the average size, i.e., the weight in deniers of the raw silk thread per 450 meters. One denier equals 5 centigrams.

Section 2. Apparatus.—The measuring machine for making the 450-meter sizing skeins shall have a reel 112½ centimeters in circumference (400 revolutions = 450 meters), revolving at a uniform velocity of 300 revolutions per minute; provided with a dial showing the number of revolutions and equipped with an automatic stop motion to stop the reel abruptly in case the thread breaks and when the skein is complete. The balance for determining the total weight of the skeins shall be capable of being read to 5 centigrams. The balance for weighing the individual test skeins should be of the quadrant type, graduated in ¼ deniers.

Section 3. Samples.—The *sample for the test* and the *sampling for the lot* shall be taken as specified in Article 1, Section 3.

Section 4. Test.—From the ten sample skeins, ten bobbins, one from each skein, shall be wound, five from the outside and five from the inside. The ten bobbins shall be placed upright on the measuring machine, and three test skeins, 450 meters each, reeled from each bobbin, a total of 30 sizing skeins. The sizing test skeins, may be taken from the bobbins wound in the winding test if desired. The room in which the reel is located should have temperature and humidity control regulated to maintain a standard atmosphere, and the silk should be in as nearly standard condition as possible at the time of reeling. The tension on the thread should be sufficient to hold it taut without excessive stretching. Care should be exercised to see that no short test skeins are reeled by the stop motion failing to act quickly upon breaking of thread or long skeins by running over 400 revolutions. The sizing skeins which lose moisture during reeling should be allowed to remain in the standard atmosphere for a sufficient time (about one hour) to allow them to return to standard condition, and then they should be weighed as follows: (*a*) *Regular Sizing.*—If the standard condition assumed by the sizing skeins in the reeling room is sufficiently accurate, the thirty skeins should be weighed together and their final weight expressed in deniers. Each skein should then be weighed on a quadrant balance to the nearest half denier, and the sum of the individual weighings should not differ from the total weight by more than one-half (½) denier. (*b*) *Conditioned Sizing.*—If a more accurate average size than the regular sizing is desired, the sizing skeins should, after completion of the regular sizing, be placed together in a conditioning oven, dried to constant weight at 130° C.–140° C., and weighed in the dry, hot atmosphere.

Section 5. Record.—The record should show the number of sample skeins drawn; the number of sizing skeins reeled and weighed; the total weight of the test skeins in deniers; the average weight per skein, i.e., the average size in deniers; the weight of the individual skeins arranged in the order of increasing magnitude, and the sum of the individual weighings. *Conditioned Sizing.*—In addition to the record made for the regular sizing, the record of the conditioned sizing should show the total dry weight in deniers, the total conditioned weight in deniers (i.e., the dry weight plus 11 percent), and the average conditioned weight per test skein, i.e., the average conditioned size in deniers.

Article 4.—American Sizing Test (225 meter)

Section 1. Object.—The American sizing test is intended to determine the variation in weight, in deniers, of 225-meter lengths of the thread, the average weight in denier of 225 meters of the thread and the average size, i.e., the weight in deniers per 450 meters.

Range.—The range for a test is the difference in deniers between the weight of the lightest and heaviest 225-meter test skein in the test. The range for a lot is the difference between the lightest and heaviest test skein in the lot.

Section 2. Apparatus.—The measuring machine for making the 225-meter test skeins, the balance for determining their total weight, and the balance for weighing the individual skeins shall be as specified for the *sizing test.* (Art. 3, Sec. 2.)

Section 3. Samples.—The *sample for the test* and *sampling for the lot* shall be taken as specified in Article 1, Section 3.

Section 4. Test.—From the ten sample skeins, ten bobbins (one from each skein) shall be wound, five from the outside and five from the inside. The ten bobbins shall be placed upright on the reeling machine, and six test skeins, 225 meters each, reeled from each bobbin, a total of sixty test skeins. The test skeins may be taken from the bobbins wound in the winding test if desired. The room in which the reel is located should have temperature and humidity control regulated to maintain standard atmosphere and the silk be in as nearly standard condition as possible at the time of reeling. The test skeins which lose moisture during reeling should be allowed to remain in the standard atmosphere for a sufficient time (about one hour) to allow them to return to standard condition and then they should be weighed as follows: *Weighing.*—The sixty test skeins should be weighed together and their total weight expressed in deniers. Each skein should then be weighed on a quadrant balance to the nearest half denier. *Conditioned Sizing.*—If the conditioned size is desired the skeins may then be placed in a drying oven, dried to constant weight at 130° C. to 140° C., and weighed in the dry, hot atmosphere.

Section 5. Record.—The record should show the number of sample skeins drawn; the number of test skeins wound; the total weight of the test skeins; the average weight of the test skeins; the weight of the individual test skeins arranged in order of increasing magnitude; the sum of the individual test skeins and the difference between the weight of the lightest and heaviest test skeins expressed in deniers, i.e., the range. The average size may be calculated by multiplying the average weight of the test skeins by two or by dividing the total weight of the sixty skeins by 30.[1]

Article 5.—Gage Test

Section 1. Object.—The gage test is intended to measure the reeling defects in raw silk and consists of a determination of the number and kind of defects in a given length of the thread.

Section 2. Apparatus.—The gage consists of two pieces of hardened tool steel approximately $6\frac{1}{2}$ inches long, 1 inch wide, and $\frac{1}{2}$ inch thick. One narrow side of each piece is ground accurately to a plane straight surface and the two pieces are bolted together so that the plane surfaces form a very narrow V-shaped slit. The gage is graduated to read in deniers by determining fixed points at which the width of the V-slit is equal to the calculated diameter of raw silk of a selected denier and by dividing the distance along the gage into equal spaces. Ten gages constitute a set which is

[1] The range found for 225-meter skeins cannot be converted into the "spring" ("ecart") in 450-meter skeins by multiplying by 2 nor by doubling the weight of the lightest and heaviest 225-meter skein and taking their difference. Such a calculation would assume that the extreme fine and coarse portion from which the lightest and heaviest 225-meter skeins were reeled continued for another 225 meters. This is not a safe assumption for the reason that the "spring" (ecart) determined by the 450-meter sizing test is always less than double the range found by the 225-meter test upon the same silk.

mounted on a reeling machine in such a manner as to be adjusted to allow the silk as it passes through guides from bobbins on to a measuring reel, to run through the gages at its average denier as determined by a sizing test.

Section 3. Evenness Defects.—(a) Weak threads (tender or fine) are those which break 30 percent to 50 percent below the average strength of the thread. (b) Very weak threads (tender or fine) are those which break 50 percent or more below the average strength of the thread. (c) Coarse threads are those which catch and break in the gages and of which the strength is 30 percent to 50 percent above the average strength of the thread. (d) Very coarse threads are those which catch and break in the gages and of which the strength is 50 percent or more above the average strength of the thread.

Section 4. Cleanness Defects.—On account of the unequal importance of the different cleanness defects in the manufacturing and finishing processes and in their effect upon the quality of the finished goods, cleanness defects are divided into two classes, viz., major defects and minor defects.

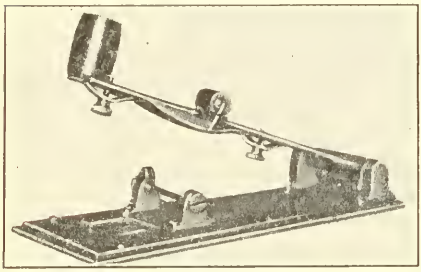


FIG. 146.—Seem Apparatus for Testing the Cohesion of Raw Silk.

(*a*) *Major Defects:*

(1) Waste is a mass of tangled open fiber attached to the raw silk thread.

(2) Slugs are thickened places several times the diameter of the thread, of $\frac{1}{8}$ inch or over in length.

(3) Bad casts are abruptly thickened places on the threads due to the cocoon filament not being properly attached to the thread.

(4) Split threads are large loops, loose ends, or open places on the thread where one or more cocoon filaments are separated from the thread.

(5) Very long knots are knots which have loose ends exceeding $\frac{1}{2}$ inch in length.

(6) Corkscrews are places on the thread where one or more cocoon filaments are longer than the remainder and wrap around the thread in spiral form.

(*b*) *Minor Defects:*

(1) Nibs are small thickened places less than $\frac{1}{8}$ inch in length.

(2) Loops are small open places in the thread caused by the excessive length of one or more cocoon filaments.

(3) Long knots are knots which have loose ends from $\frac{1}{4}$ to $\frac{1}{2}$ inch in length.

(4) Raw knots are the necessary knots for tying breaks in the raw silk thread during the reeling and re-reeling operation. The ends of the knot should be less than $\frac{1}{8}$ inch long. The number of raw knots should be recorded, but they should not be counted among the defects.

Section 5. Samples.—The sampling for the test and the sampling of the lot shall be as specified in Article 1, Section 3.

Section 6. Winding.—Sufficient silk for the test shall be wound from the sample skeins onto bobbins under the same conditions as specified in the winding test in Article 2, Sections 3 and 4. A record shall be kept of the number of winding breaks and care should be exercised to tie all winding breaks without removing any of the thread, with a distinguishing knot (bow knot) in a manner to be easily recognised. The silk wound onto bobbins in the winding test, Article 2, may be used for the gage test, provided care is exercised to tie all winding breaks with a distinguishing knot (bow knot) so that the nature of the defect causing the winding break may be determined and recorded.

Section 7. Test.—The bobbins shall be placed upright on the gage reeling machine and the ends of the threads passed through guides and the gages with just sufficient tension to keep the thread taut. The gages shall be adjusted to such a position that the thread will run through them at the average size. The thread speed should be approximately 250 yards per minute. When the thread breaks the reel should be stopped and both ends of the thread examined to determine the kind of defect as defined by Section 3 of this article, and illustrated by standard photograph adopted by the Silk Association of America. If either portion appears fine or coarse it should be tested on a serimeter to determine if it is an evenness defect. (Section 3 (a), (b), (c), (d).) When 1,000 yards have been wound from each of the ten bobbins (10,000 yards in all), the reel should be stopped and a record made of the number of defects in each class. The test should be continued until a total of 30,000 yards has been reeled, stops and records being made of each 10,000 yards.[1]

Section 8. Records.—The records of the test shall show the number of each defect for each 10,000 yards reeled, the total number of each defect for the total number of yards tested, and the number of defects of each kind calculated for 100,000 yards.[2]

Article 6.—Serimeter Test for Evenness

Section 1. Object.—The serimeter test for evenness is made to determine the variation of the breaking points of one hundred different portions of the raw silk thread from the average breaking point found by taking the average of the hundred points tested.

Section 2. Apparatus.—The serimeter used for the test must be sensitive and capable of being read to one gram and have a maximum capacity of 250 grams. It must be provided with a type of clip which does not cut the thread. The pulling clip of the testing machine shall move at a uniform speed of 80 centimeters per minute.

Section 3. Sample.—The sampling for the test and the sampling of the lot shall be as specified in Article 1, Section 3. The test shall be made upon ten sizing skeins.

Section 4. Test.—Each sizing skein should be cut once, and from each of the ten sizing skeins ten strands shall be selected at random and examined to see that they appear to be clean threads (i.e., contain no cleanness defects as defined and illustrated in Article 5). The strands shall be placed in the serimeter, inspected again to make sure they are clean, and the breaking point determined. Any strands found to contain cleanness defects should be replaced by clean ones, and strands which break in the clips should not be counted. The length of thread between the clips at the beginning of each test shall be 50 centimeters.

[1] The operator should see that no waste or loose matter collects on the gages to interfere with the passage of the thread, and care should be exercised to keep the gages clean, well coated with oil to avoid rusting and protected with covers when not in use. The gages should be frequently tested to determine if the width of the slit is correct.

[2] To express the final result of the test in a single number of defects, the various defects must be included in the final result in accordance with their relative importance.

The following multiplying factors are suggested for this purpose:

Evenness Defects.—Weak threads and coarse threads may be taken as counted.

Very weak threads should be multiplied by three.

Very coarse threads should be multiplied by two.

Cleanness Defects.—Major defects are to be taken as counted.

Minor defects are to be considered as one-tenth defect and their number should be divided by ten.

Section 5. Record.—The breaking point of each strand should be read and recorded to the nearest five grams, the values being arranged in the order of increasing magnitude. The record should show the frequency, i.e., the number of breaks at, above, and below the average breaking point.[1]

Article 7.—Serigraph Test

Section 1. Object.—The serigraph test is designed to determine the tenacity, elasticity and elongation of raw silk.[2]

Definitions.—The three physical characteristics determined in this test are defined as follows: Tenacity is the strength of a single thread expressed in grams per denier. Elasticity is the limiting force expressed in grams per denier which the thread will just support without permanent elongation. It is indicated in the test by the yield point on the serigraph record at which the straight line portion ends and the diagram becomes curved. Elongation (heretofore called elasticity) is the amount that the silk is stretched when pulled to the breaking point.

Section 2. Apparatus.—The apparatus for the test consists of a tensile strength testing machine with an autographic attachment recording simultaneously the pulling force and the corresponding elongation of the thread. The machine must be located in a room having humidity and temperature control and must be capable of being tested for correctness of reading by direct loading with standard weights. The total capacity of the machine should not be greater than twice the ultimate strength of the specimen to be tested. The uniform speed of the pulling jaw should be 15 centimeters (6 inches) per minute.

Section 3. Sample.—The sample for the test and the sampling for the lot shall be taken as specified in Article 1, Section 3. The test sample shall consist of ten sizing skeins. The 450-meter skeins used in the sizing test or the 225-meter skeins used in the American sizing test may be used, but in either case the skeins should not be twisted tight enough to injure the gum, and the skeins should be opened and allowed to hang loose for some time before being tested in the serigraph. Sizing skeins which have been used for a conditioned sizing, Article 3, Section 4, cannot be used in this test on account of the possible changes in the physical properties of the thread which may have taken place due to the heating in the conditioning oven.

Section 4. Test.—The test skeins shall be placed in a space in which the relative humidity and temperature can be regulated to the standard condition and they shall remain a sufficient time (usually one to two hours) to allow them to become adjusted to a standard condition. Each skein should then be carefully weighed to the nearest $\frac{1}{4}$ denier, placed in the recording serigraph and tested for tenacity, yield point and

[1] The following arrangement will be found simple, convenient, and easily interpreted. The report blank should have a portion ruled both horizontally and vertically. Each space from the top downward may be taken equal to 5 grams, and each space across the sheet equal to 5 strands. Assigning values to the spaces vertically, the breaking point of the individual strands may be tallied beside their corresponding values, and at the completion of the test the total number of tallies for each breaking point can be entered in an adjoining space. A graphical representation of the result of the test can be easily made by drawing at each breaking point, horizontally from a fixed vertical line, a heavy line with its length indicating the number of strands breaking at that point.

[2] As a raw silk thread is pulled, it stretches at first proportionally to the pulling force, and if the pulling force is relieved the thread will return to its original length. If the force continues to increase, it will reach a point at which the thread begins to stretch more rapidly and to be permanently stretched.

elongation.[1] The length of the tested portion should be 10 cm. between the clamps of the machine when the test begins. Care should be exercised to prevent the portion of the skein which is outside of the clamps from supporting any portion of the pulling force.

Section 5. Record.—The autographic record should show a diagram from which the breaking load and elongation at any point during the test can be read with an accuracy of 5 percent, and the final reading on the dial of the testing machine should check with the breaking load, as shown on the autographic diagram. By placing a ruler along the straight line portion of the diagram, the point at which the diagram begins to depart from a straight line can be marked. This point will be called the yield point. The pulling force at the yield point, divided by the number of strands, divided by the weight of the skeins in deniers, is called the elasticity of the silk and is expressed in grams per denier. The total stretch to the breaking point, divided by the original length, is the elongation and should be expressed in percent. The tabulated record shall show the following for each skein:

(a) The number of strands tested.
(b) The weight of the skein in deniers.
(c) The breaking force in grams.
(d) The tenacity, i.e., the grams per denier.
(e) The elasticity, i.e., the pulling force in grams at the per denier at the yield point.
(f) The elongation, in percentage.

For the entire test of ten skeins: The average tenacity, the average elasticity, the average elongation.

Article 8.—Cohesion Test (By Seem's Cohesion Machine)

Section 1. Object.—The cohesion test is intended to determine the compactness of the raw silk thread and the thoroughness with which the cocoon filaments forming the thread have been agglutinated. It is based upon the amount of rolling and rubbing under constant pressure which the thread will withstand before splitting into its individual cocoon filaments.

Section 2. Apparatus.—The Seem cohesion machine consists of a hardened steel roller accurately ground and polished, approximately ¼ inch in diameter, mounted on a steel arm which is hinged at one end and which acts as the weight to produce pressure on the roller. Under the roller a steel carriage, mounted between guides, moves back and forth a distance of about 2 inches. The carriage is fitted with two clamps for holding the specimens, and a counter indicates the number of strokes which the carriage makes during the test. The roller is set at an angle of 2.5 degrees to the path of movement of the carriage so that the thread is submitted to a rolling and rubbing action.[2]

[1] The skein must be secured in the clamps of the serigraph in such a manner that all strands are held firmly and none of the threads are cut by the pressure of the clamps or any sharp edges. This can be easily accomplished by wrapping all of the strands around a strip of soft cardboard and placing the cardboard in the clamps of the machine in such a manner that all strands are securely held but not crushed. It is convenient to place the test specimen in the upper clamp of the testing machine first, then carefully draw all of the strands smooth and taut, and wrap them around a second cardboard at the position in which the lower clamp should seize the strands. Caution should be exercised to see that all strands are parallel, uniformly taut, and none excessively stretched.

[2] Great care should be exercised to keep the roller smooth, free from rust or dirt, and to see that it is properly lubricated and adjusted to turn freely but with only slight

Section 3. Sample.—The sample for the test shall consist of five skeins, and the sampling of the lot is as specified in Article 1, Section 3. The test specimen consists of fifty strands taken at intervals of not more than two yards along the thread from a single skein laid taut fifty threads per inch on a sheet of firm, unglazed black cardboard to which they are secured by means of gummed paper tape. One test specimen shall be prepared from each five sample skeins and may be taken from the bobbins of the winding test or direct from the sample skein. Raw silk which has been used for a conditioned sizing, a serimeter test, a serigraph test, or any test which affects its physical qualities, shall not be used for the cohesion test. Before being used for the test the card should be inspected to determine if the threads have any cleanness defects or pronounced unevenness in the portion which is to be tested. Imperfect threads should be removed before starting the test and in case the strands are noticeably uneven the card should be rejected and another card made.

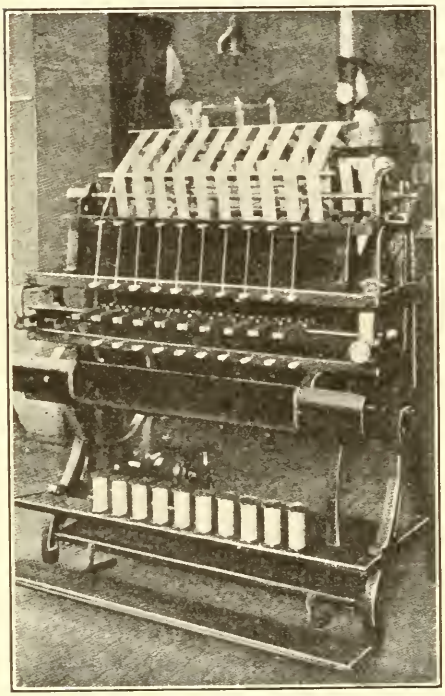


FIG. 147.—Seem Gage in Operation Attached to a Special Reeling Machine.

Section 4. Test.—The sample cards should be kept in a standard atmosphere for at least one hour after preparation to insure that the thread is in standard condition. The testing machine should be operated in a room where the relative humidity and temperature can be maintained at standard condition during the test. The test cards should be clamped in the machine in such a manner as to lie flat and smooth and the threads parallel with the direction of movement of the carriage. The machine should run at a uniform speed of 120 strokes per minute, and there should be no evidence of jumping or jerking at the end of the stroke. As the test proceeds, the threads should be inspected occasionally. As they begin to open, frequent examinations, at least every fifty strokes, should be made to determine when all are completely open.[1]

Section 5. Record.—The record of the test should show the number of cards tested, the number of strokes necessary to open all of the threads on each card, and the average number of strokes.[2]

endwise motion. When not in use, the roller should be covered with a film of vaseline or oil to prevent rusting, but the film must be thoroughly removed with alcohol or gasoline before beginning a test.

[1] The openness of the thread can be conveniently determined by removing the card from the machine, inserting a thin piece of metal between the thread and the card and slightly raising the thread off the card.

[2] In cases where the threads do not appear to be opening uniformly and a small number (five or less) indicate that they will require a much larger number of strokes to open them, the test may be considered complete when 90 percent of the threads are open.

CHAPTER XI

CHEMICAL NATURE AND PROPERTIES OF SILK

1. Chemical Constitution.—The glands of the silkworm appear to secrete two transparent liquids. The one: **fibroine,** constituting from one-half to two-thirds of the entire secretion, forms the interior and larger portion of the silk fiber; the other, **sericine,** also called *silk-glue,* forms the outer coating of the fiber. The latter substance is yellowish in color, and is readily soluble in boiling water, hot soap, and alkaline solutions. As soon as they are discharged into the air, the fluids from the spinneret solidify, and coming into contact with each other at the moment of discharge are firmly cemented together by the sericine.

The amount of sericine present in raw silk is about 23 percent, and this causes the fiber to feel harsh and to be stiff and coarse. Before being manufactured into textiles, the raw silk is subjected to several processes with a view to making it soft and glossy. The first treatment is called *discharging, stripping,* or *degumming,* and has for its purpose the removal of the silk-glue. It is really a scouring operation, the silk being worked in a soap solution at a temperature of 205° F.[1] In this process thrown silk loses from 20 to 30 percent in weight, but becomes soft and glossy. Alkaline carbonates are not to be recommended for silk scouring, as they are liable to injure the fiber, especially at elevated temperatures. Soft water should also be employed, as lime makes the fiber brittle.

Piece-dyed silk goods, like plain and figured pongees, satins, and similar fabrics, are, as a rule, woven with silk in the gum state, the fabrics being afterwards boiled-off or ungummed. This, however, is not possible with fancy colored fabrics.

After several successive scourings the soap solution becomes heavily charged with sericine, and is subsequently utilised in the dye-bath as an assistant, under the name of **boiled-off liquor.**

According to the report of the conditioning house at Lyons for the year 1908, the average boil-off losses for various kinds of silks were as follows:

[1] Soap foam and also certain mineral oil emulsions are also very good degumming agents for silk.

Yellow Silks.	Percent.	White Silks.	Percent.
French	24.18	French	21.54
Italian	23.40	Piedmont	20.68
Piedmont	22.92	Italian	21.40
Spanish	24.94	Brusa	21.92
Syrian	24.35	China	17.98
Bengal	22.09	Canton	22.17
		Japanese	17.90

Chittick gives the following boil-off losses for various kinds of raw silk:

	Percent.
Japans, white	18–21
" yellow	21–23
Italians, white	20–22
" yellow	20–23
China, steam filature	20–23
Tsatlees	20–24
Cantons	20–23
Tussahs	8–14

It may be said, therefore, that the boil-off of raw silk varies from 18 to 23 percent, depending on the origin of the silk. The boil-off loss, however, of thrown silk, which is most generally the form in which the dyer and bleacher receives the silk, is usually considerably higher than that of raw silk. It generally runs about 24 to 27 percent, and this is due to the fact that in throwing the silk it is soaked in emulsions of oil and soap in order to soften up the gum, and in this way the fiber may absorb 2 to 5 percent of these ingredients, which are, of course, subsequently removed in the complete boil-off.

According to Mulder, samples of yellow Italian silk analysed as follows:

	Percent.
Silk fiber	53.35
Matter soluble in water	28.86
" " alcohol	1.48
" " ether	0.01
" " acetic acid	16.30

He gives the chemical composition of the silk fiber as follows:

	Percent.
Fibroine	53.37
Gelatine	20.66
Albumen	24.43
Wax	1.39
Coloring matter	0.05
Resinous and fatty matter	0.10

According to Richardson, mulberry silk has the following composition:

	Percent.
Water	12.50
Fats	0.14
Resins	0.56
Sericine	22.58
Fibroine	63.10
Mineral matter	1.12

Suzuki, Yoshimura, and Inouye [1] give the following analyses of samples of various Japanese raw silks:

	Bombyx Mori, Percent.	Sakusan, Percent.	Yama-mai, Percent.	Kuri-wata, Percent.
Moisture	12.90	13.16	11.29	11.71
Dry substance	87.10	86.84	88.71	88.29
100 parts dry fiber yielded:				
Ash	0.63	2.92	4.73	3.85
Soluble in boiling HCl	99.14	92.21	97.07	88.34
Insoluble in boiling HCl	0.86	7.79	2.93	11.66
Total nitrogen	18.98	18.87	17.73	16.73
Nitrogen soluble in HCl	18.86	16.39	17.26	15.77
Nitrogen insoluble in HCl	0.12	2.48	0.47	0.96
100 parts of the total nitrogen showed:				
Nitrogen soluble in boiling HCl	99.34	86.87	97.34	94.26
Ammonia nitrogen	4.57	2.52	3.85	4.08
Nitrogen ppt. by phosphotungstic acid	1.78	13.11	19.44	15.54

Chittick points out that since the boil-off of Japan silk is lower than that of any other important silk, this is of considerable advantage when such silk is employed in piece dyeing, for the cloth will be 8 to 10 percent heavier than the same character of cloth made from yellow silk; also if the silk is dyed in the skein and weighted the amount of real silk in the thread will be greater than with silks showing a higher percentage of boil-off. In actual practice in the dyehouse, the amount of boil-off will usually be somewhat less than that which may actually be found in the

[1] *Jour. Coll. Agric. Imp.*, Univ. Tokio, 1909, p. 59.

laboratory by a complete boil-off test, for in the dyehouse too severe a treatment in the boil-off is to be avoided, as this may cause the individual filaments of the fiber to be opened up, and the dyed silk may be soft, spongy, and hairy. Severe treatment in the boil-off may also cause "lousiness" in the fiber, a condition due to the splitting of the individual cocoon filaments into minute fibrillae.

According to Chittick the percentage of weighting in skein-dyed silk will vary considerably with the boil-off, consequently the boil-off factor becomes an important consideration in the treatment of silk, for it will be seen that the ounces of weighting that may be ordered from the dyer will form no guide as to the figure representing the actual amount of weighting unless the boiled-off conditioned weight of the thrown silk is known. It is obvious, therefore, that the only manner of calculating the exact degree of weighting is to ascertain the conditioned boiled-off weight of the thrown silk sent to the dyer and then to order on that basis whatever percentage of weighting is desired. Chittick gives the following table showing the actual percentage of weighting according to the variations in the boil-offs:

Weighting Ordered Ozs.	Weight Returned by Dyer. Lbs.	Boil-offs, Percentage.										
		20	21	22	23	24	25	26	27	28	29	30
		Actual Weighting, Percentage (on Boiled-off Weighting).										
14	0.875	9	11	12	14	15	17	18	20	22	23	25
16	1.000	25	27	28	30	32	33	35	37	39	41	43
18	1.125	41	42	44	46	48	50	52	54	56	58	61
20	1.250	56	58	60	62	64	67	69	71	74	76	79
22	1.375	72	74	76	79	81	83	86	88	91	94	96
24	1.500	88	90	92	95	97	100	103	105	108	111	114
26	1.625	103	106	108	111	114	117	120	123	126	129	132
28	1.750	119	122	124	127	130	133	136	140	143	146	150
30	1.875	134	137	140	144	147	150	153	157	160	164	168
32	2.000	150	153	156	160	163	167	170	174	178	182	186
36	2.250	181	185	188	192	196	200	204	208	213	217	221
40	2.500	213	216	221	225	229	233	238	242	247	252	257
44	2.750	244	248	253	257	262	267	272	277	282	287	293
48	3.000	275	280	285	290	295	300	305	311	317	323	329
52	3.250	306	311	317	322	328	333	339	345	351	358	364
56	3.500	338	343	349	355	361	367	373	379	386	393	400
60	3.750	369	375	381	387	393	400	407	414	421	428	436

Analyses of samples of mulberry silk are given by H. Silbermann [1] as follows:

	White.		Yellow.	
	Cocoons, Percent.	Raw, Percent.	Cocoons, Percent.	Raw, Percent.
Fibroine	73.59	76.20	70.02	72.35
Ash of fibroine	0.09	0.09	0.16	0.16
Sericine	22.28	22.01	24.29	23.13
Wax and fat	3.02	1.36	3.46	2.75
Salts	1.60	0.30	1.92	1.60

Silbermann also gives a table showing the difference in the elementary composition between mulberry silk and tussah silk:

	Mulberry Silk.		Tussah Silk.	
	Cocoon Threads, Percent.	Fibroine, Percent.	Cocoon Threads, Percent.	Fibroine, Percent.
Carbon	36.77	47.47	46.96	48.50
Hydrogen	6.21	6.37	6.26	6.34
Nitrogen	17.57	17.86	17.60	18.37
Oxygen	28.25	28.01	26.39	26.39
Ash	1.20	0.29	2.85	0.40

The amount of ash in boiled-off silk will vary somewhat according to the origin of the silk, but will average about 0.50 percent. In raw silk the average amount of ash will be about 1 percent. In yama-mai silk the ash may reach as high as 8 percent. Allen [2] states that the greater part of the mineral matters of raw silk are simply adherent to the fiber, and are removed together with the sericine by prolonged boiling with soap solution; the residual fibroine retains only about 0.6 percent of mineral matter.

[1] *Die Seide*, vol. 2, p. 210.
[2] *Commercial Organic Analysis*, vol. 4, p. 507.

2. Fibroine.—This substance is a proteid somewhat analogous to that contained in wool, and, like the latter, is no doubt an amino-acid. Mulder gives the analysis of fibroine as follows:

	Percent.
Carbon	48.80
Hydrogen	6.23
Oxygen	25.00
Nitrogen	19.00

Vignon analysed samples of highly purified silk, and gives the following figures:

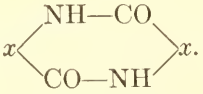
	Percent.
Carbon	48.3
Hydrogen	6.5
Nitrogen	19.2
Oxygen	26.0

Vignon prepares pure fibroine in the following manner: A 10-gram skein of raw white silk is boiled for thirty minutes in a solution of 15 grams of neutral soap in 1500 cc. water; rinse in hot, then in tepid water; squeeze and repeat the treatment in a fresh soap-bath; rinse with water, then with dilute hydrochloric acid, again with water; finally, wash twice with 90 percent alcohol. The fibroine thus obtained leaves only 0.01 percent of ash on ignition.[1]

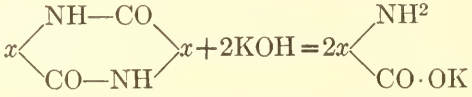
A mean of analyses by a number of well-known investigators on the composition of fibroine is as follows:

	Percent.
Carbon	48.53
Hydrogen	6.43
Nitrogen	18.33
Oxygen	26.67

Richardson suggests the following structural formula for fibroine, allowing x to represent a hydrocarbon residue:



The decomposition of fibroine by saponification with potash would then be



[1] *Compt. rend.*, vol. 115, pp. 17, 613.

3. Amount of Fibroine in Raw Silk.—According to Allen[1] raw commercial silk from the mulberry silkworm is generally regarded as containing 11 percent of moisture, 66 percent of fibroine, 22 percent of sericine, and 1 percent of mineral and coloring matters.

The proportion of fibroine in raw silk has been variously stated by different observers, and appears to differ with the method employed for its determination. The figure given by Mulder (see above) of 53.35 percent was obtained by boiling the raw silk with acetic acid. By the action of a 5 percent solution of cold caustic soda, Städeler obtained 42 to 50 percent of fibroine. Cramer obtained 66 percent by heating raw silk in water at 133° C. under pressure. Francézon reports 75 percent of fibroine by twice boiling the silk in a solution of soap and then treating with acetic acid. Vignon, by carefully purifying the fibroine by suitable treatment, obtained 75 percent. According to Fischer and Skita[2] even technically purified silk still contains about 5 percent of silk-glue.

In the Report of the Milan Commission on Silk (1906) it was concluded that very great differences existed in the proportion of fibroine given by silks from the same races of *Bombyx mori*, depending on conditions of food, culture, etc. Variations in the amount of fibroine from 73 to 84 percent have been recorded, and hence it is impossible to base an estimate of the purity of silk upon the results of such a determination. Owing to the fact that the amount of substances soluble in a soap solution varies from 16 to 27 percent, it is obviously possible to add to this amount by artificial means. The permissible limits of impurities were determined by the commission by analyses of a large number of samples of known purity. From these analyses the following table was prepared:

	Minimum, Percent.	Maximum, Percent.	Mean, Percent.
Substances soluble in 3 percent soap solution	21.449	25.913	22.865
In distilled water at 50°–55° C	0.447	1.053	0.617
In ether	0.104	0.451	0.275
Ash	0.726	0.903	0.855

The amount of soluble gum in Japanese raw silk averages about 18 percent; in China silk about 19 percent; in yellow Europeans about 22 percent; and in tussah silk of good quality about 15 percent; while low-grade tussahs will lose much more.

[1] *Commercial Organic Analysis*, vol. 4, p. 506.

[2] *Zeitschr. physiol. Chem.*, vol. 33, p. 171, and vol. 35, p. 224.

4. Chemical Properties of Fibroine.—Unlike keratine, the proteid of wool, fibroine contains no sulfur, and is much more constant in its composition. The empirical formula for fibroine as given by Mulder is $C_{15}H_{23}N_5O_6$. Mills and Takamine give the formula as $C_{24}H_{38}N_8O_8$, while Schützenberger gives $C_{71}H_{107}N_{24}O_{25}$. Cramer arrives at the same formula as Mulder, while Richardson [1] gives $C_{60}H_{94}N_{18}O_{25}$. Vignon's formula for specially purified fibroine is $C_{22}H_{47}N_{10}O_{12}$.

Silbermann found that fibroine heated with a solution of barium hydrate under pressure was decomposed with the formation of oxalic, carbonic, and acetic acids, together with an amino-body approximating the formula $C_{68}H_{141}N_{21}O_{43}$. The latter compound is said to undergo further decomposition with the formation of tyrosine, glycocine, alanine, amino-butyric acid, and an amino-acid of the acrylic series. Fischer and Skita [2] have shown that in all probability amino-valerianic acid, $C_3H_7 \cdot CH(NH)_2 \cdot COOH$, occurs in fibroine. Silk fibroine, however, appears to differ from other albumens in not containing aspartic acid, $COOH \cdot CH_2 \cdot CH(NH_2) \cdot CO \cdot OH$. Glutaminic acid, $COOH \cdot CH_2 \cdot CH_2 \cdot CH(NH_2) \cdot COOH$, also appears to be present in fibroine, though Fischer doubts this.

The presence of the amino-group in fibroine has been shown, as in the case of wool, by diazotising the fiber with an acid solution of sodium nitrite, then washing and treating with solutions of various developers, such as phenol, resorcinol, alpha- and beta-naphthols, etc., whereby the fiber becomes dyed in different colors.

From its action toward alcoholic potash Richardson concludes that silk fibroine is probably an amino-anhydride rather than an amino-acid. When boiled for a long period with dilute sulfuric acid, fibroine is dissolved to a yellowish brown liquid, leaving as a residue only a small amount of what is apparently a fatty acid. From this decomposition product Weyl succeeded in isolating 5.2 percent of tyrosine, 7.5 percent of glycosine and 15 percent of a crystalline compound which was apparently alpha-alanine.

Toward Millon's and Adamkiewitz's reagents fibroine gives the usual reaction of proteids, and it also gives the biuret test.

Millon's reagent consists of a solution of mercurous nitrate containing nitrous acid in solution. It is prepared by treating 1 cc. of mercury with 10 cc. of nitric acid (sp. gr. 1.4), heating gently until complete solution is effected, then diluting the solution with twice its volume of cold water. When a solution of a proteid is treated with this reagent, a white precipitate is first formed, which turns brick-red on boiling; a solid proteid becomes red when boiled with the reagent. Adamkiewitz's test is to dissolve the

[1] *Jour. Soc. Chem. Ind.*, vol 12, p. 426.

[2] *Zeitschr. f. physiol. Chem.*, vol. 33, p. 177.

proteid in glacial acetic acid, and then add concentrated sulfuric acid to the solution, when a fine violet color will be produced, and the liquid will exhibit a faint fluorescence. The biuret test is to add a few drops of a dilute solution of copper sulfate to the solution of proteid; then on adding an excess of caustic soda solution the precipitate which at first formed will be dissolved with the production of a fine violet coloration.

According to Richardson, silk fibroine will absorb 30 percent of iodine when treated with Hübl's reagent. Attempts have been made to acetylise fibroine, but without success.

Cohnheim, in his tables of the percentage composition of various albumens, gives the following for the fibroine of silk:

	Percent.
Glycocoll	36.0
Alanine	21.0
Leucine	1.5
Phenylalanine	1.5
α-Pyrrolidine carboxylic acid	0.3
Serine	1.6
Tyrosine	10.0
Arginine	1.0

The occurrence of the following compounds in indeterminate amounts is also given: Lysine, histidine, tryptophane, and amino-valerianic acid.

The following table gives the products of hydrolysis obtained from various kinds of silk:

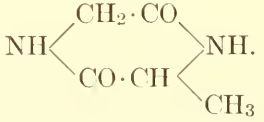
	Bombyx Mori.		Raw Sakusan, Percent.	Raw Yama-mai, Percent.	Raw Kuri-wata, Percent.	Raw Tussah, Percent.
	Fibroine, Percent.	Sericine, Percent.				
Glycocoll	36.0	0.1-0.2	5.7	6.3	7.7	35.13
Alanine	21.0	5.0	4.8	7.2	15.3	23.4
Leucine	1.5	....	1.2	1.3	7.95	1.76
Proline	0.3	....	.....	.....	4.0	3.68
Glutaminic acid	....	....	.....	0.6	?	6.16
Asparaginic acid	....	....	1.0	1.0	0.2	
Tyrosine	12.0	5.0	1.4	2.0	5.5	4.2
Histidine	....	....	2.7	1.6	1.01	
Arginine	1.0	4.0	3.1	3.8	1.74	5.24
Ammonia	1.05	1.87	0.6	0.8	0.8	1.16

Fibroine is insoluble in ammonia and solutions of the alkaline carbonates; neither is it dissolved by a 1 percent solution of caustic soda, but

stronger solutions affect it, especially if hot. From its solution in caustic soda fibroine may be reprecipitated by dilution with water. Fibroine is also soluble in hot glacial acetic acid, and in strong hydrochloric, sulfuric, nitric, and phosphoric acids. Alkaline solutions of the hydroxides of such metals as nickel, zinc, and copper also dissolve fibroine.

If silk fibroine is dissolved in cold concentrated hydrochloric acid, and the solution be allowed to stand sixteen hours at the ordinary temperature with three times its volume of hydrochloric acid (sp. gr. 1.19), it will no longer be precipitated by the addition of alcohol. The fibroine appears to have suffered hydrolysis, being converted into a body similar to peptone. This substance may be separated out by steaming the above solution under diminished pressure. If its aqueous solution be neutralised with ammonia and some trypsine ferment be added, tyrosine will begin to crystallise out in a few hours.

Fischer and Abderhalden [1] have succeeded in isolating from the hydrochloric acid solution of silk fibroine a dipeptide in the form of methyldiketopiperazine, having the formula



The yield is about 12 percent, and the product is identical with that obtained synthetically from glycocoll and *d*-alanine.

5. Sericine.—According to the analysis of Richardson, sericine has the following composition:

	Percent.
Carbon	48.80
Hydrogen	6.23
Oxygen	25.97
Nitrogen	19.00

and its formula is given as $C_{16}H_{25}N_5O_8$. It is considered by some as an alteration product of fibroine, strong hydrochloric acid is said to convert the latter into sericine, the conversion is supposed to take place by assimilation of water and oxygen.

$$\underset{\text{Fibroine.}}{C_{15}H_{23}N_5O_6} + H_2O + O = \underset{\text{Sericine.}}{C_{16}H_{25}N_5O_8}.$$

Sericine may be obtained in a pure condition by first boiling a sample of raw silk in water for several hours, after which the sericine is pre-

[1] *Berichte*, 1906, p. 752.

cipitated by lead acetate. Pure sericine may also be prepared by precipitating crude sericine solution with 1 percent acetic acid, washing the separated sericine by repeated decantation with water, then treating with cold and afterwards with boiling alcohol, and finally extracting with ether. Pure sericine contains

	Percent.
Carbon	45.00
Hydrogen	6.32
Nitrogen	17.14
Oxygen	31.54

It is easily soluble in water, in concentrated hydrochloric acid, and in potassium carbonate; sodium carbonate only causes a swelling.

On treatment with dilute sulfuric acid, sericine yields a small quantity of leucine and tyrosine, but no trace of glycocoll, the principal product formed being a crystalline body called *serine*, which appears to have the formula $C_2H_4\begin{cases}NH_2\\COOH\end{cases}$, and from its chemical reactions is evidently analogous to glycocine probably being amino-glyceric acid.

Sericine is soluble in hot water, hot soap solutions, and dilute caustic alkalies. The aqueous solution is precipitated by alcohol, tannin, basic lead acetate, stannous chloride, bromine, and iodine, and by potassium ferrocyanide in the presence of acetic acid. By treatment with formaldehyde, it is claimed that sericine is rendered insoluble in both hot water and soap solutions; consequently, raw silk may be treated with this reagent for use in certain applications where it may be desired to retain as far as possible the coating of silk-glue.

Mulder gives the formula of $C_{15}H_{25}N_5O_8$ to sericine and the following composition:

	Percent.
Carbon	42.60
Hydrogen	5.90
Oxygen	35.00
Nitrogen	16.50

According to Bolley, the composition of sericine is

	Percent.
Carbon	44.32
Hydrogen	6.18
Oxygen	31.20
Nitrogen	18.30

According to the tables of Cohnheim, the percentages of known constituents in silk-glue are as follows:

	Percent.
Glycocoll	0.1–0.2
Alanine	5
Leucine	Not determined
Serine	6.6
Tyrosine	5
Lysine	Not determined
Arginine	4
Ammonia	1.87

Vignon,[1] by observing the action of solutions of sericine and fibroine on polarised light, found that both of these constituents of silk were laevogyrate, and their rotatory powers were about equal, approximating to 40°. This is in keeping with observations made on other albuminoids.

6. Coloring Matter.—According to Dubois the yellow coloring matter of silk is similar to carotin. He obtained five different bodies from the natural coloring matter of silk, as follows: (1) A golden-yellow coloring matter, soluble in potassium carbonate and precipitated by acetic acid; (2) crystals which appear yellowish red by transmitted light and brown by reflected light; (3) a lemon-colored amorphous body, the alcoholic solution of which on evaporation gave granular masses; (4) yellow octahedral crystals resembling sulfur; (5) a dark bluish green pigment in minute quantities and probably crystalline.

Levrat and Conte [2] have shown that the color of natural silk is due to the coloring matter present in the leaves on which the silkworms feed; chlorophyl being the coloring matter in the case of green silks, while yellow silks contain the yellow coloring matter of the mulberry leaves. These investigators made experiments by feeding silkworms with leaves stained with various artificial dyes, and it was found that the silk produced was more or less colored. The silk from the *Atlacus orizaba* give a more pronounced color than that from the ordinary silkworm.

7. Chemical Reactions: Heat.—In its general chemical behavior silk is quite similar to wool. It will stand a higher temperature, however, than the wool fiber, without receiving injury; it can be heated, for instance, to 110° C. without danger of decomposition; at 170° C., however, it is rapidly disintegrated. On burning it liberates an empyreumatic odor which is not as disagreeable as that obtained from burning wool.

8. Action of Water.—Silk is a highly absorbent fiber and readily becomes impregnated or wetted by water. Dissolved substances present in the

[1] *Compt. rend.*, vol. 103, p. 802.
[2] *Jour. Soc. Chem. Ind.*, vol. 2, p 172.

water also are rather readily absorbed or taken up by the silk; therefore, it is easy to understand that hard and impure waters are sources of contamination for silk goods with which these waters come in contact during processes of washing, dyeing, or finishing. The softness and luster of the fiber is quite easily affected by these impurities; consequently it is to be recommended that wherever water is employed in connection with silk that the water be as soft as possible. So thoroughly is this fact realised at the present time that most modern silk factories use water softened by the zeolite process whereby the hardness may be reduced practically to zero. The character of the water employed in reeling silk from the cocoons is also said to have considerable influence on the quality of the silk produced. The best results are obtained when as soft a water as possible is used.

9. Action of Acids.—Silk readily absorbs **dilute acids** from solutions, and in so doing increases in luster and acquires the scroop of which mention has previously been made. Unlike wool, it has a strong affinity for **tannic acid,** which fact is utilised for both weighting and mordanting the fiber.

The reaction between silk and tannic acid is different from that with other textile fibers. Heermann [1] points out that vegetable fibers absorb only small amounts of tannic acid, a state of equilibrium being produced which depends on the relative amounts of water, tannic acid, and fiber. The tannic acid absorbed by vegetable fibers is also readily removed by cold water.[2] Wool absorbs but little tannic from cold solutions, and when treated with hot solutions the fiber becomes harsh. The silk fiber, however, behaves somewhat like hide in that it absorbs a large amount of tannic acid from cold solutions, and as much as 25 percent of its weight from a hot solution. Furthermore, the tannin absorbed by silk is not readily removed by treatment with water. Heermann experimented on the absorption of various tannins by silk, the following tannins being employed: Gambier, gambier substitute, Aleppo gall extract, sumac extract, and divi-divi extract; the samples of silk used for the purpose being (1) pure silk which had been degummed, (2) silk dyed with Prussian blue, and (3) silk mordanted with tin chloride and sodium phosphate. The following conclusions were deduced: Most tannin is absorbed by all three samples of silk from the gambier extract; pure silk absorbs almost as much from gall extract and from sumac extract, but the prepared samples of silk showed only a slight absorption of these two tannins. Divi-divi comes next to gambier in amount of absorption. Gambier substitute is peculiar, as tannin is absorbed from it only when the solutions are concentrated.

[1] *Färb. Zeit.*, 1908, p. 4.

[2] See Knecht and Kershaw, *Jour. Soc. Chem. Ind.*, 1892, p. 129; also Georgievics, *Mitt. des tech. Gewerbe Museums in Wien*, 1898, p. 362.

Concentrated sulfuric and hydrochloric acids dissolve silk; nitric acid colors silk yellow, as in the case with wool, probably due to the formation of xanthoproteic acid. This color can be removed by treatment with a boiling solution of stannous chloride. The action of nitric acid on silk is rather a peculiar one. When treated for one minute with nitric acid of sp. gr. 1.33 at a temperature of 45° C., the silk acquires a yellow color which cannot be washed out and is also fast to light. Pure nitric acid free from nitrous compounds, however, does not give this color. On treating the yellow nitro-silk with an alkali, the color is considerably deepened. Vignon and Sisley [1] found that the purified fibroine of silk when treated with nitrous nitric acid increased 2 percent in weight.

With strong sulfuric acid nitro-silk swells up and gives a gelatinous mass resembling egg albumen. The solubility of silk in strong hydrochloric acid is very rapid, a minute or two sufficing for complete solution. Under such conditions wool and cotton fibers are but slightly affected, hence such a treatment may be used for the separation of silk from wool or cotton for the purpose of analysis. Though silk is soluble in concentrated acids if their action is continued for any length of time, it appears that if silk be treated with concentrated sulfuric acid for only a few minutes, then rinsed and neutralised, the fiber will contract from 30 to 50 percent in length without otherwise suffering serious injury beyond a considerable loss in luster. This action of concentrated acids on silk has been utilised for the crêping of silk fabrics, the acid being allowed to act only on certain parts of the material. It appears that tussah silk is not affected by the acid to the same degree as ordinary silk, and hence crêping may be accomplished by mixing tussah with ordinary silk, and treating the entire fabric with concentrated acid.

Hydrofluosilicic acid and hydrofluoric acid in the cold and in 5 percent solutions do not appear to exert any injurious action on the silk fiber; these acids, however, remove all inorganic weighting materials, and their use has been suggested for the restoring of excessively weighted silks to their normal condition, so that they may be less harsh and brittle.

According to Farrell [2] when silk is treated with hydrochloric acid of a density of 29° Tw. it shrinks about one-third without any appreciable deterioration in the strength of the fiber. With solutions of acid below 29° Tw. no contraction occurs, while with solutions above 30° Tw. complete disintegration of the fiber results. In the production of crêpon effects by this method, the fabric is printed with a wax resist, and is then immersed in the hydrochloric acid; the contraction is complete in one to two minutes, after which the fabric is well washed in water. Nitric acid and ortho-phosphoric acid may also be employed for the crêping of silk

[1] *Compt. rend.*, 1891.

[2] *Jour. Soc. Dyers & Col.*, 1905, p. 70.

fabrics.[1] According to a French patent a similar effect may be obtained by treating silk with a solution of zinc chloride of from 32° to 76° Tw.[2]

When silk is treated at ordinary temperatures, with 90 percent formic acid, the silk swells and contracts and becomes gelatinous, and can be drawn out into threads which, however, have not much strength. The action is complete in two or three minutes. If the acid is then drained off and the silk is thrown into water, the rinsing restores it nearly to its original condition with sufficient elasticity to enable it to be stretched to its original length with the hands. On drying silk so treated, it becomes stiffer and generally more lustrous, without any loss of tensile strength. The original shrinking varies from 8 to 12 percent of the length before treatment. Formic acid has the same action on natural silks, whether degummed or not; but chappe silk, which is not very strong to begin with, may lose somewhat in strength. The treatment has very little effect on tussah. The best results are obtained with grège, whether degummed or not, treating with 90 percent formic acid for five minutes, and then rinsing thoroughly. The degumming may then follow with 20 percent of olive oil soap in the usual way. The hank shortens by 8 to 12 percent and loses weight in the same proportion on the average, but the loss of weight depends on the quality of the original silk. This contraction of the fiber, so similar to that of cotton under the influence of caustic soda, has given rise to many attempts to enhance the luster of the silk itself by treating it exactly on Lowe's lines, using, of course, formic acid instead of caustic soda. These attempts have met with a certain amount of success for bringing up the luster of inferior silks, but the tendering of the fiber is often considerable, and the new luster is not altogether agreeable to the eye. The tendering is also associated with fraying of the fiber and also with the formation of lumps caused by the cohesion of the frayed parts. On treating half-silk (silk and cotton) with formic acid, the fabric is crêped by the shrinking, without the injury to the silk that would result from the use of caustic soda, but the process is expensive.

10. Action of Alkalies.—Silk is not as sensitive to dilute alkalies as wool, though the luster of the fiber is somewhat diminished. It is said that when mixed with glucose or glycerol caustic soda does not dissolve the silk fiber to any extent, but only removes the gum. When treated with strong hot caustic alkalies the silk fiber dissolves. Ammonia and soaps have no effect on silk beyond dissolving the silk-glue or sericine; though on long-continued boiling in soap, the fibroine is also attacked. Borax has no injurious action on silk, but neither has it any special solvent action on silk-glue, hence it is not serviceable as a stripping agent. If raw silk is steeped in lime-water, the fiber will swell to some extent and

[1] See C. and P. Depoully, *Jour. Soc. Dyers & Col.*, 1896, p. 8.

[2] *Jour. Soc. Dyers & Col.*, 1899, p. 214.

the silk-glue will become somewhat softened. If the action of the lime-water is continued, however, the silk will become brittle.

11. Action of Metallic Salts, etc.—Toward the ordinary metallic salts used as mordants silk exhibits quite an affinity; in fact, to such an extent can it absorb and fix certain metallic salts that silk material is frequently heavily mordanted with such salts for the purpose of unscrupulously increasing its weight.

The tensile strength of weighted silk is often less than that of the pure silk; and furthermore, the weighting materials sometimes causes a rather rapid deterioration of the fiber. Strehlenert [1] has shown that the strength of black dyed silk weighed to 140 percent was less than one-sixth that of the pure raw silk. White and colored silks are usually weighted with tin phosphate and silicate, and this may cause the fiber gradually to become brittle and to disintegrate. Reddish spots frequently develop on such weighted silk, probably resulting from the action of salt contained in the perspiration from the workman handling the material. By treating tin weighted silk with preparations containing ammonium sulfocyanide, glycerol, and tannin, the rapid deterioration of the silk may be largely prevented. Sunlight seems to accelerate the destructive action of tin weighting, though according to Silbermann this effect is much reduced if stannous salts are absent. Gianoli [2] states that this reactivity of the tender silk is not due to the presence of stannous salts, but rather to decomposition products of the silk, resulting from the effects of oxidation and hydrolysis upon the silk fibroine. These decomposition products are soluble in water and include ammonia and other nitrogenous compounds. When exposed to sunlight in a vacuum or in an atmosphere of an inert gas, the fiber does not become tender, but is seriously affected when the exposure is carried out in the presence of air or moisture. In this connection Silbermann recommends the following test to detect the presence of the stannous compound. The sample of silk is heated with an acidified solution of mercuric chloride; if tin in the stannous condition is present, mercurous chloride will be deposited on the fiber and will yield a dark gray sulfide when treated with hydrogen sulfide. Silbermann also concludes that the presence of ferrous salts in the iron mordants used for black dyed silk has a similar destructive action on the fiber.

Treatment of weighted silk (tin-silico-phosphate method) with thiourea and with hydrosulfite-formaldehyde compounds also decreases the tendering action of the weighting material, and such processes are now in commercial use.

Hydroquinone sulfonate is also employed to prevent the deterioration of weighted silk. The amount required is from $\frac{1}{2}$ to 5 percent of sodium

[1] *Chem. Zeit.*, 1901, p. 400.
[2] *Chem. Zeit.*, 1910, p. 105.

salt of hydroquinone sulfonate and is applied in solution as an after-treatment to the weighted silk. Ammonium sulfocyanide is usually employed directly in the tin bath itself, from ½ to 3 percent of the salt being used.

Solutions of **sodium chloride** appear to have a peculiar action on the silk fiber, especially in the presence of weighting materials. According to the researches of Sisley, solutions of common salt acting on weighted silk in the presence of air and moisture cause a complete destruction of the fiber in twelve months, if charged with but 0.5 percent of salt; 1 percent of salt causes a very pronounced tendering of the fiber in two months, while 2 to 5 percent of salt causes a distinct tendering in seven days. The action of the salt is shared in a lesser degree by the chlorides of potassium, ammonium, magnesium, calcium, barium, aluminium, and zinc, and is probably due to chemical dissociation. This fact may account for the stains sometimes found in skeins of silk which also show a tendering of the fiber. These stains have frequently been noticed, and thorough investigation has failed to satisfactorily account for them. The salt may get into the fiber through the perspiration of the workmen handling the goods, or through a variety of other causes.

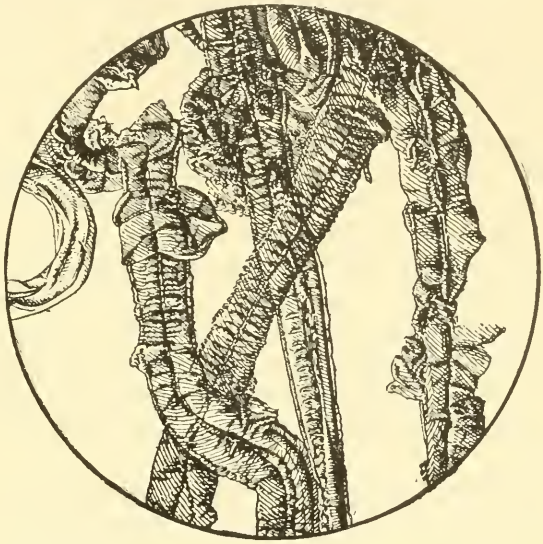


FIG 148.—Raw Silk in Schweitzer's Reagent. (×100.) (After Herzog.)

A concentrated solution of **basic zinc chloride** readily dissolves the silk fiber. On diluting this solution with water a flocculent precipitate is obtained which is soluble in ammonia, and the latter solution has been employed for coating vegetable fibers with silk for the production of certain so-called "artificial silks." An acid solution of zinc chloride acts in the same manner. Solutions of **copper oxide** or **nickel oxide** in ammonia also act as solvents toward silk. The latter solution can be employed for separating silk from cotton, the silk being readily and completely soluble in a boiling solution of ammoniacal nickel oxide, whereas cotton loses less than 1 per cent of its weight. A boiling solution of basic zinc chloride

(1 : 1) will dissolve silk in one minute, while cotton under the same treatment loses only 0.5 percent, and wool only 1.5 to 2 percent. Silk is also soluble in **Schweitzer's reagent** (ammoniacal copper oxide), and in an alkaline solution of copper sulfate and glycerol. The latter is used to separate silk from wool and cotton; and the following solution is recommended: 16 grams copper sulfate, 10 grams glycerol, and 150 cc. of water. After dissolving, add a solution of caustic soda, until the precipitate which at first forms is just redissolved. **Chlorine** destroys silk, as do other oxidising agents, unless employed in very dilute solutions and with great care. Strong solutions of **stannic chloride** (70° Tw.) will dissolve silk, an action which should be borne in mind when mordanting and weighting silk with this salt. Silk also absorbs **sugar** to a considerable degree, and this substance may be employed as a weighting material for light-colored silks on this account.

12. Action of Dyestuffs.—Toward coloring matters in general, silk exhibits a greater capacity of absorption than perhaps any other fiber. It also absorbs dyestuffs at much lower temperatures than does wool.

As silk is evidently an amino-acid, it possesses distinct chemical characteristics; that is to say, it exhibits both acid and basic properties in a manner similar to wool. Like the latter fiber it is probable that the active chemical groups in silk have considerable influence on its dyeing properties, especially with reference to acid and basic dyes, for it has been shown that if these active molecular groups are rendered inactive by acetylation or otherwise, the dyeing properties of the silk are accordingly altered.

Sansone [1] states that if silk is treated cold for two or three minutes with 90 percent formic acid solution it rapidly swells, softens, and becomes viscous. From comparative dye tests it would seem that the treated silk has a greater affinity for substantive dyestuffs and for metallic mordants. This result was confirmed with treated silk which had been subsequently neutralised with sodium carbonate solutions, thus proving that the increased affinity is not caused by free formic acid remaining in the fiber, but by change in the physical nature of the silk itself. With basic and acid dyes the increase in affinity is much less marked. Many artificial silks, and more especially viscose silk, show a similar change in dyeing properties after a formic acid treatment but an immersion of several hours is necessary to produce the effect.

13. Weighting of Silk.—The discovery of tin weighting marks a turning point in the development of the silk industry. The secrecy in which the process was originally shrouded prevented the name of its discoverer from being handed down, just as was the case later with the fixing of tin with phosphoric acid, and with the silicate method of weighting. Several

[1] *Rev. Gen. Mat. Col.*, 1911, p. 194.

points come into consideration in discussing the effects of tin weighting, and these are:

(1) Of all metallic salts, those which have the greatest affinity for silk are the salts of tin.

(2) This affinity enables the fiber to assimilate enormous quantities on repeated weighting.

(3) Any tin load on the silk will serve as a foundation for other weightings which the silk could not otherwise take up.

(4) Tin weighting has no effect upon the color of the fiber, and permits it to be dyed any conceivable hue.

(5) A tin loading properly used, and reasonable in amount, has a most beneficial effect both upon the luster and on the handle of the silk, and does but little injury to its strength, elasticity, or durability.

While most metallic compounds suitable for silk-weighting are taken up by the fiber to the extent of a few percent at most, some of them less than 1 percent, silk takes up on the average from 8 to 10 percent of its weight of oxide of tin from a suitable tin solution. In weighting silk with tin and sodium phosphate, for each 2 ozs. of weighting the silk must be given one pass through the tin bath. The discovery of these high figures of tin caused the trial of nearly every other metal for silk-weighting. Those of high atomic weight, especially lead, gave good results, which seemed very promising, especially as lead is so much cheaper than tin. All these expectations, however, were doomed to disappointment, and not even the great increase in the cost of tin, even prior to the war, was able to check the development of it suse for silk-weighting. It was already known that repeated metallic baths gave an increased weighting, with tannin the silk became quickly saturated, and therefore unsusceptible to any further action. As many as ten, or even fifteen, iron baths were not uncommonly given, and if the fixed oxide of iron is converted into Prussian Blue the silk will then take up still more of the metal. Although chromium weighting can be increased by repeated baths, there is no action with ferrocyanide analogous to that which forms Prussian Blue in the case of iron, and chromium salts are dearer than iron salts as well. Hence they are not used on silks except as mordants for dyes. Alumina is taken up by silk to a small extent only, and the amount is not increased by repeating the bath.

The degree of weighting in silks varies with the character of the goods. For cheap black fabrics, heavy ribbed or gros grains, where the filling is entirely covered, weighting up to 49 ozs. is used for the filling yarns. For black goods of fair quality, the warp may be weighted to 20 to 26 ozs. and the filling 26 to 30 ozs. For colored goods with tin weighting it is not safe to go above 18 ozs. for the warp and 24 ozs. for the filling. According to Chittick, the limits of judicious weighting are 16 ozs. for organzine and 22 ozs. for tram. Above these limits the silk is liable to deteriorate too soon.

Treatment with sodium phosphate after the tin bath was a great advance in the art of silk-weighting. Before its time the tin was fixed in soda, ammonia, or some other alkali. Although the rinsing after the tin bath does most of the fixing, the alkali is necessary to remove the traces of acid left in the silk. This residual acid, although it only amounts to from 1.14 to 1.7 percent, practically prevents any further weighting in a fresh bath. After neutralisation, the fiber, which itself acts as a weak alkali, can take up a fresh lot of tin. Now the hydrated oxide of tin which is precipitated on the fiber is a free base, and injures the silk considerably on exposure to air and light. If, however, the oxide is neutralised by combination with phosphoric acid, not only are the durability and strength of the silk increased instead of being diminished, but the expense of the weighting is made less. Other acids have been tried, but none answers so well as phosphoric. Boric acid proved absolutely useless, and although some chemists held out bravely for tungstic acid, relying on its high molecular weight, it had to yield to phosphoric. Tannic acid, which gives good weightings with oxide of tin, can only be used after the last bath, and is unsuitable for many dyes.

Another discovery was that silicate of soda formed an excellent foundation for weighting, and again we are ignorant of where, or by whom, the discovery was made. It is quite certain that it much increases the tin phosphate weighting when used together with it. The discovery was published first in Germany, in H. J. Neuhaus's patent of January 25, 1903. Hotly contested lawsuits have shown, however, that Neuhaus was not the first to work the process in Germany, and that it had been known and worked for about a year before he patented it. The patent therefore became void, and the process common property. Great as is the amount of tin absorbed by silk, the use of the silicate of soda makes it still greater. Weightings up to 40 percent are obtained, but the silicate is useless except on a foundation of oxide or phosphate of tin.

It is known that metallic weightings injure the silk very much under certain circumstances, but it is also certain that the extent of the injury is not always proportional to the degree of weighting, but that small weighting is often more injurious than much heavier loads of other kinds, i.e., that the nature of the weighting is as important as its amount. Experience has taught, in short, that stable and inert bodies are best, especially when associated with an organic body such as tannin. Hence a tin phosphate load is better than one of a free metallic oxide, and yet better if accompanied by tannin. Inasmuch, however, as it is sometimes inadvisable to use phosphoric acid, and sometimes objectionable to use tannin, a great variety of loading processes have been invented, each being fitted for some special purpose.

Weighted silk is more susceptible to deterioration by the action of

various agents than untreated silk. High temperatures, such as are sometimes reached in the course of finishing operations, may cause a dehydration of the weighting materials and thus produce weakness in the fiber. Chlorides are particularly active in causing tenderness in weighted silk. Meister and Gianoli have both shown that this destructive action of chlorides could be more or less completely neutralised by treating the silk with potassium or ammonium sulfocyanate. Sisley [1] has shown that sulfocarbamide can be used with even better advantage. The amount of the reagent to use is about 3 percent on the weight of the silk. This method is now quite largely employed in the treatment of weighted silks and the protective effect is quite remarkable. The economic side of weighting is of great importance on account of the high price of tin. All waste of tin must be prevented. In the early days of tin weighting, metal was lost by throwing away the rinse water after wringing. Soon, however, means were found for recovering the tin from the rinse in the form of oxide. This saves as much tin as goes into the silk. Special machinery, too, has been invented to enable the baths to be used to greater advantage, to save waste by dripping, etc., and, by means of pressure and centrifuging, to remove as much as possible of the excess of liquor for use on more silk, before it is diluted by rinsing. The rinse water may also be used for making fresh weighting baths. Heermann [2] states that the conclusion of Bayerlein, that metastannic acid is at no time formed in the weighting of silk, is unfounded; the amount of metastannic acid in tin baths increases as the concentration decreases. The opalescence observed in tin solutions is due to metastannic acid. The most reliable test for metastannic acid in this connection is the white voluminous precipitate which appears in a solution containing a calcium salt upon being made alkaline, and this does not disappear on heating.

In the practical working of the silicate weighting it was soon found that it was advantageous to intervene with a bath of alumina or zinc between the last phosphate and the last silicate bath. If this extra bath is used in moderation, the valuable qualities of the silk are not perceptibly affected, but a considerable increase in the weighting is cheaply attained. Following out this experience, manufacturers substituted baths of other metals for the successive tin baths, to a greater and greater extent, until at last only the first metal bath was of tin. This has led to many variations in the weighting process which can be traced in the patents concerned with them. Lead, bismuth, nickel, copper, manganese, and antimony have all been tried.

Another direction which research has taken is toward fixing oxide of tin on the fiber in the form of various insoluble salts of organic and inor-

[1] *Rev. Gen. Mat. Col.*, vol. 13, p. 33

[2] *Färb. Zeit.*, 1910, p. 318.

ganic acids by the use of all manner of soluble salts of the acids; no useful result has been achieved along this line. Yet another consists in trying to fix inert bodies upon the silk by means of albumen, glue, etc., made insoluble with formaldehyde, or with a salt of iron or chromium. These last processes have the advantage that the fiber is not injured so far as its strength and elasticity are concerned, but have the drawback that they impart an utterly unnatural appearance to the silk, as soon as any weighting worth having has been incorporated. The luster is entirely ruined, as the surface of the silk is effectually masked. Finally, the cost of these loadings is great in proportion to the increase in weight given to the silk.

All these researches have been virtually useless, and manufacturers are going back more and more to loading with tin, in combination with phosphoric, silicic, and tannic acids. The only practical success that has been achieved is to replace a little of the tin by alumina.

The best way to apply the tin is probably in the form of chloride, although tin sulfite (*Ger. Pat.* 30,597) is in some respects superior to the chloride. It gives more metal to the fiber. A very recent invention (*Ger. Pat.* 163,322) is to combine the tin chloride with sulfates, especially glaubersalt and sulfate of alumina, but there has not yet been sufficient experience of the process to enable us to judge of its value.

Chittick calls attention to the fact that the real amount of weighting—that is, the percentage of adulterant added to the silk fiber, will depend on the amount of gum, soap, and oil that the thrown silk loses in the boil-off. Most manufacturers have no real idea of the amount of loading they are putting on their silks, as they seldom have a boil-off test made on their thrown silk. If silk, for example, was ordered to be weighted 22/24 ozs. (which means that 16 ozs. of thrown silk when dyed must weigh not less than 22 ozs. nor more than 24 ozs.) it might happen that one lot of Japan silk would have a natural boil-off of 16 percent, that 2 percent of soap and oil had been added by the throwster, and that the weight returned by the dyer might be just 22 ozs. Another lot might have a natural boil-off of 20 percent, the throwster might have added 4 percent of soap and oil, and the return from the dyer might be the full 24 ozs. Now the manufacturer thinks that both silks are weighted the same, yet the first lot would have been actually weighted only 67.68 percent, whereas the second lot would be loaded 97.36 percent.

As regards the influence of tin weightings, whether simple or mixed, upon dyeing, they are all perfectly suitable for any color, and both for cuit and souple silks. The black-dyer is less dependent than others on the weighting, as he uses substances like tannin and iron salts, which themselves act as loaders. These bodies are barred to the color dyer for the most part, as they darken the fiber, and he is confined to bleached tannin, alumina, and colorless salts. Tannin is dear, always darkens the fiber, and

does not give enough weight alone, although it gives far more than alumina or salts. In short, modern silk-dyeing is impossible without tin weighting. Tin can be applied at any stage of the preparation of the silk, or raw silk, to souple, or to boiled-off silk. Tinned raw silk can be scoured, without losing more tin than corresponds to the percentage of bast removed. It can be mordanted with iron, alumina, or chrome, and can be further weighted with Prussian Blue, and finally it can be dyed with natural coloring matters, or the coal-tar dyes.

Silk-weighting is the basis of modern silk-dyeing. Any serious struggle against it is a hopeless fight against natural development and progress, is based on mistaken ideas, and can only be useful against an exaggerated and irrational loading of the fiber.

14. Tussah Silk presents a number of differences, both physical and chemical, from ordinary silk. It has a brown color and is considerably stiffer and coarser. It is less reactive, in general, toward chemical reagents, and consequently presents more difficulty in bleaching and dyeing. Tussah silk requires a much more severe treatment for degumming than cultivated silk, and the boiled-off liquor so obtained is of no value in dyeing.

Tussah, or tussur, silk is largely used in the weaving of a pile fabric known as "sealcloth," which consists of a tussah silk plush woven into a cotton back, and is a material of most useful character for wraps and mantles. It is a fabric having a rich and handsome appearance, and, if injured by wetting or pressing, is readily restored by drying before a fire and brushing. Tussah silk is also extensively used for rug and carpet making, and as its fiber is nearly three times as thick as mulberry silk it gives a much firmer and better pile. It is also used in the manufacture of woven cloths such as "Mandarine" and "Grenadine" fabrics. It furthermore finds extensive use for fringes, damasks, millinery pompons, tassels and cords, chenille for upholstery, and for embroidery silks.

According to analyses of Bastow and Appleyard,[1] raw tussah silk gives the following results:

	Percent.
Soluble in hot water	21.33
Dissolved by alcohol (fatty acid)	0.91
Dissolved by ether	0.08
Total loss on boiling off with 1 percent solution of soap	26.49
Mineral matter	5.34

These same observers consider that the fibroine of tussah silk differs chemically from that of ordinary silk, as it is not so readily acted on by solvents. In order to obtain pure tussah fibroine, the silk should be boiled repeatedly with a 1 percent solution of soap, washed with water, extracted with hydrochloric acid; and after again washing with water and drying, extracted

[1] *Jour. Soc. Dyers & Col.*, vol. 4, p. 88.

successively with alcohol and ether. Tussah fibroine purified in this manner shows the following composition:

	Percent.
Carbon	47.18
Hydrogen	6.30
Nitrogen	16.85
Oxygen	29.67

These figures are exclusive of 0.226 percent of ash. Appleyard gives the following analysis of the ash from raw tussah silk.

	Percent.
Soda, Na_2O	12.45
Potash, K_2O	31.68
Alumina, Al_2O_3	1.46
Lime, CaO	13.32
Magnesia, MgO	2.56
Phosphoric acid, P_2O_5	6.90
Carbonic acid, CO_2	11.14
Silica, SiO_2	9.79
Hydrochloric acid, Cl	2.89
Sulfuric acid, SO_3	8.16

The presence of sulfates in this ash is somewhat remarkable, as this constituent does not occur in ordinary silk. The occurrence of alumina is also remarkable, as this element is seldom a constituent of animal tissues. As the amount of ash of purified fibroine of both common silk and tussah silk is very much lower than that of the raw silks, it is to be considered probable that most of the mineral matter found is derived from adhering impurities, and is not a true constituent of the silk itself.

Tussah silk is scarcely affected by an alkaline solution of copper hydrate in glycerol, whereas ordinary silk is readily soluble in this reagent.[1]

Shroff [2] describes the properties of a variety of oriental wild silk in the manufactured form. The cloth examined is often spoken of as "Kashmere silk," and was of a yellow-reddish tint. It was almost entirely unaffected by concentrated hydrochloric acid, chromic acid and zinc chloride, all of which dissolved mulberry silk. The action of boiling 10 percent caustic soda was slow. Soda ash, and soap, both followed by hydrogen peroxide, partly bleached it, reducing the luster. Hydrogen peroxide and sodium silicate preserved the luster and were equally good in reducing the color. The best result was obtained by boiling with 1° Tw. hydrochloric acid, then treating with 3° Tw. caustic soda for a few minutes and finally with $\frac{1}{2}$° Tw. ammonium hypochlorite, washing after each.

The following table exhibits the principal differences between true silk and tussah silk:[3]

[1] Filsinger, *Chem. Zeit.*, vol. 20, p. 324.

[2] *Posselt's Text. Jour.*, 1922.

[3] Bastow and Appleyard, *Jour. Soc. Dyers & Col.*, vol. 4, p. 89.

Reagent.	Mulberry Silk.	Tussah Silk.
Hot caustic soda (10 percent)	Dissolves in 12 minutes	Requires 50 minutes for solution
Cold hydrochloric acid (sp. gr. 1.16)	Dissolves very rapidly	Only partially dissolves in 48 hours
Cold conc. nitric acid	Dissolves in 5 minutes	Dissolves in 10 minutes
Neutral solution of zinc chloride (sp. gr. 1.725)	Dissolves very rapidly	Dissolves but slowly
Strong chromic acid solution in water	Dissolves very rapidly	Dissolves very slowly

While the fiber of mulberry silk presents the appearance of a structureless thread, and rarely exhibits signs of distinct striation, tussah (as well as other " wild " silks) is made up of bundles of delicate fibrillæ, varying in diameter from 0.0003 to 0.0015 mm., so that the fiber as a whole presents a striated appearance. Also the cross-section of tussah silk is considerably larger than that of mulberry silk, and is more flattened; it also exhibits numerous fine air-tubes. The following table exhibits the difference in the microscopic appearance of various kinds of raw silk:[1]

Variety of Silk.	Diameter, Microns.	Appearance.	
		Broad Side.	Narrow Side.
True silk, *Bombyx mori*	20 to 25	White or yellowish; shiny	White or yellowish; shiny
Senegal silk, *B. faidherbi*	30 to 35	Shining yellowish or brownish white, or pale yellow, gray, brown, and occasionally bluish white	Gray, brown, or black, with occasionally lighter shades
Ailanthus silk, *Attacus cynthia*	40 to 50	Shining yellowish white, with yellow, brown, or brownish gray spots	Dirty gray or brown to black, with green, yellow, red, violet, or blue spots
Yama-mai silk, *Antheræa yama-mai*	40 to 50	Bluish white with dark blue, blue and black shades	Glaring and fine colors, with dark or black shades
Tussah silk, *Attacus selene*	50 to 55	Irregular in thickness. Thickest parts with gray and blue spots; thinner parts bluish white, yellow, or orange-red	Dark gray, with pink or light green spots
Tussah silk, *Antheræa mylitta*	60 to 65	Similar to above, but spots orange-red, red, or brown	Similar to above

[1] Höhnel, *Jour. Soc. Chem. Ind.*, vol. 2, p. 172.

The cocoon-thread of wild silks possess greater elasticity and tensile strength, as would naturally be expected from their greater thickness. The following table gives the elasticity and breaking strain of the principal varieties of silk:

Variety of Silk.	Elasticity, Percent.	Breaking Strain, Grams.
Mulberry (*Bombyx mori*)	13.3	4.5
Tussah (*Antheræa mylitta*)	19.1	12.8
Eria (*Attacus ricini*)	15.0	4.0
Muga (*Antheræa assama*)	21.7	6.7
Atlas (*Attacus atlas*)	19.1	5.6
Ailanthus (*Attacus cynthia*)	22.5	4.9
Yama-mai	25.0	12.8
Attacus selene	20.0	5.6
Antheræa pernyi	19.1	8.1

Muga (or *moonga*) silk is a wild silk next in importance and value to tussah. It is indigenous to Assam, but is also to be found in some other provinces. The fiber is fawn-colored when the worm feeds on the common plants in the districts of which it is a native, but gives a whiter and better quality of fiber when fed on leaves on which other silkworms are reared. Champa-fed worms produce the celebrated *champa pattea moonga*, a very fine quality of white silk used only by the rajahs.

Eria silk is, perhaps, the third in importance among the wild silks. It is produced by a worm which feeds on the castor-oil plant, and like the muga silk is indigeneous to Assam, but is also found in other districts. In Assam the fiber is white, but in Singapore it is brown. Eria silk does not dye very readily, being inferior in this respect to tussah. Owing to its rather loose cocoon, eria silk cannot be reeled, but has to be spun after being combed.

Other varieties of wild silk are the *Bombyx textor*, known as the " pat " silkworm, a native of Assam. It is probably a variety of the *B. mori*, though its cocoon is of a different shape and is yellow in color. The silk is of excellent quality and is quite valuable.

The *Cricula trifenestrata* is abundant in British Burma, where the cocoons literally rot in the jungles for want of gathering. The silk is strong, rich and lustrous; it is spun in the same way as Eria silk and is yellow in color.

15. Byssus Silk.—This is also known as " sea-silk " or " pinna silk," and is obtained from a marine mollusk, *Penna nobilis*, and related varieties. The shell-fish possesses a long slender gland which secretes woolly fibers known as the *Byssus* or " beard." These fibers are of a brown color and

are 4 to 6 cm. in length. The brown color is said to be due to an external covering which when removed leaves a colorless fiber. Sea-silk is somewhat used in southern Italy and in Normandy for the making of various ornamental braided articles. Though this fiber somewhat resembles silk in appearance, it is easily distinguished by the presence of natural rounded ends. The fibers vary considerably in diameter (10 to 100 microns) and are ellipitical in cross-section (Fig. 149), and are often twisted. Fine longitudinal striations are apparent, but as the fiber is solid no empty lumen or air canals are present. The finer fibers are smooth, but the

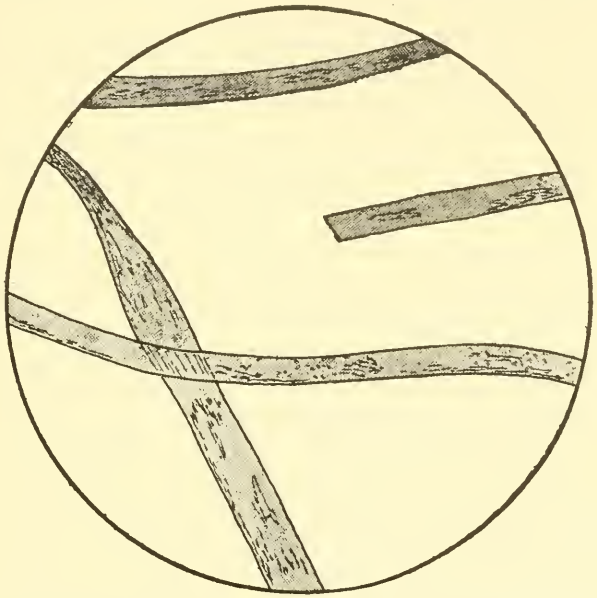


FIG. 149.—Fiber from *Penna nobilis*. (×100.) (Micrograph by author.)

coarser ones are rough and corroded. Frequently very delicate fibrils are to be observed branching from the larger fibers.

The manufacture of materials from pinna silk was carried on at Taranto in Italy. The " fish wool " (as it was called) was washed twice in water, once in soap and water, and again in tepid water, and finally spread out on a table to dry. While yet moist it was rubbed and separated with the hands and again spread on the table to dry. When quite dry it was drawn through a wide bone comb and then through a narrow one. It was then spun into a yarn with distaff and spindle. As it was not possible to procure much of the material of good quality the manufacture was limited to a few articles such as gloves and stockings, and these were

quite expensive. The fabrics were very soft and warm and of a brown or glossy gold color.[1]

Another animal fiber of a somewhat silklike nature is the so-called "*sinew fiber*." This product is obtained from sinews which consists of fibrous connective tissue made up of wavy elements united in bundles. Hanausek [2] calls attention to the fact that sinew fiber was utilised in ancient times, the Israelites using a yarn twisted from sinews under the name of "gidden" for their religious rites. In recent years sinew fiber has been spun into yarns by mixing with wool or hemp. The fiber is very silky in luster and varies much in length (from 3 to 18 cm.). Such yarns have great tensile strength and are rough in feel.

[1] Gilroy, *History of Silk*, etc., p. 182.
[2] *Microscopy of Technical Products*, p. 150.

CHAPTER XII

THE VEGETABLE FIBERS

1. Origin of Vegetable Fibers.—Probably there is no one thing more used in common life and with which the average individual comes more in contact than vegetable fibers. These materials are used broadly for all kinds of clothing and underwear, for household fabrics, for sheetings and towelings, and for all manner of purposes far too numerous to mention; and yet outside of the fact that the material is cotton or linen—and even this fact may sometimes be in doubt—it is questionable if the layman is at all familiar with the general nature and structure of these vegetable fibers.

All vegetable tissues are made up of cells, and in most cases these cells are very minute in size and delicate in structure. This is true of vegetable fiber as well as of other tissues of the plant. Cotton is rather remarkable in this connection, as it consists of a single elongated cell, and in its intimate structure, therefore, differs quite radically from linen and most other vegetable fibers, in that these consist of a bundle or number of individual small cells that, cemented together by other vegetable tissue, go to make up the commercial fiber.

Jute, hemp, China grass, as well as the various cordage fibers, belong in the same category as linen as far as structure is concerned. These all consist of a large number of tiny cells compacted together to form an individual fiber. It is easy to understand, therefore, why a weakening of the fiber is caused in such cases by subjecting it to processes of bleaching or other chemical treatments. The effect is usually to dissolve or disintegrate the cementing layers that hold the cells together, and thus the fiber is weakened and broken up into its small elements. Cotton, being a single integral cell, is thus more capable of resisting the action of such agents than the other fibers.

The basis of all vegetable fibers is to be found in **cellulose**, a compound belonging to a class of naturally occurring substances known as **carbohydrates.** It is seldom, however, that cellulose actually occurs in the plant in the free condition, but is usually associated or chemically combined with other substances, of which the principal are fatty and waxy matters, coloring matters, and tannins, and a rather indefinite group of so-called pectin matters, which appear to be more or less oxidised or acid derivatives

of the carbohydrates. The fibers may be **seed-hairs,** such as the different varieties of cotton, cotton-silk, etc.; or **bast fibers,** which include those obtained from the cambium layer of the dicotyledonous plants, such as flax, hemp, jute, ramie, etc.; or **vascular fibers,** which include those obtained chiefly from the leaf-tissues of the monocotyledonous plants, such as phormium, agave, aloe, etc.

The terms "dicotyledonous" and "monocotyledonous" refer to plants the seeds of which have two lobes and one lobe respectively. A dicotyledonous plant is also an exogen or outside grower, familiar examples of which are ordinary trees or shrubs. Monocotyledonous plants, on the other hand, are endogens, or inside growers, such as grasses, palms, lilies, etc. The stalk of the monocotyledonous plant is really the residue of the successive leaf-sheaths, whereas the stalk of the dicotyledonous plant is a separate growth entirely distinct from the leaf. In China there is an example of a spinning fiber composed of the *leaf-hairs* of a plant. The latter apparently belongs to the *Xeranthemum,* and its leaves are covered with a thick mass of long hairy fibers, which are easily separated from the leaf when dried. There is peculiar instance in which the entire plant is used as the fiber; this is sea-grass or sea-wrack (*Zostera marina*). However, it can scarcely be considered as a textile fiber, as it is almost together employed for stuffing and packing.

Anatomically considered, the plant fibers may be divided into six different classes (Höhnel):

1. Seed-hairs of a single cell, such as cotton, vegetable silk, and vegetable down.
2. Seed-hairs consisting of several cells, such as pulu fiber, elephant-grass, and cotton-grass.
3. Bast fibers, such as flax, hemp, jute, ramie, etc.
4. Dicotyledonous bast fibers, such as linden bast, Cuba bast, etc.
5. Monocotyledonous vascular fibers, such as sisal hemp, aloe hemp, pineapple fiber, cocoanut fiber, etc.
6. Monocotyledonous sclerenchymous fibers, such as Manila hemp, New Zealand flax, etc.

Depending on the portion of the plant from which the fiber is derived, the following classification may be used:

1. *Seed* fibers, growing from the seeds or seed-capsules of certain plants, and including cotton, vegetable silk, etc.
2. *Stem* fibers, growing in the bast of certain dicotyledonous plants, and including flax, hemp, jute, etc.
3. *Leaf* fibers, occurring in the leaves of a number of monocotyledonous plants, and including New Zealand hemp, Manila hemp, aloe, etc.
4. *Fruit* fibers of which the sole member worth mentioning is the cocoanut fiber.

2. Seed-hairs and Bast Fibers.—There is considerable difference to be observed between the anatomical structure of seed-hairs and that of

bast fibers. **Seed-hairs** are known botanically as plumose fibers, and usually consist of a unicellular fiber exhibiting only a single solid apex, the other end being attached to the seed. Externally they appear to be covered with a thin skin or cuticle which differs essentially from the remaining cellulose in that it is not dissolved by treatment with sulfuric acid. The cell-walls vary considerably in their thickness, and are structureless and porous. Through the center of the fiber runs a hollow canal called the *lumen*. Usually the dried fiber is flattened into the form of a band, so that in cross-section the lumen appears as a line. The inner surface of the cell-wall is also coated with a very thin layer of dried protein matter which is very adhesive, and which remains undissolved like the cuticle after the solution of the fiber in sulfuric acid. **Bast fibers,** on the other hand, consist of completely enclosed tubes, each end being pointed. Each individual fiber is multicellular, the cells being long and usually polygonal in cross-section. The cell-walls are usually rather thick, and the cross-section instead of being flat and narrow is broad and more or less rounded. The inner wall is frequently covered with a thin layer of dried protein. The bast or vascular bundles consist of two parts, the *phloëm* and the *xylem*. As a rule, the phloëm occurs nearer the outside of the plant, while the xylem forms the principal structural part of the inside portion of the plant. The fibers in the phloëm are usually rather easily detached and form the commercial product, while those occurring in the xylem, as a rule, cannot be readily separated by mechanical means from the woody tissue in which they are imbedded.

One of the most characteristic appearances of the bast fibers is the occurrence of *dislocations* or joints throughout the length of the fiber (Figs. 150 and 151). These dislocations show the property of becoming more deeply colored than the rest of the fiber when treated with a solution of chlor-iodide of zinc. These knots or joints generally show thicker overlying transverse fissures, between which lie small short disks arranged on edge. The joints disappear altogether in the sclerenchymous or leaf fibers such as New Zealand flax, Manila hemp, sisal, etc.; they are also lacking on many true bast fibers, such as jute, linden bast, etc.; but occur in hemp, flax, ramie, etc. These joints or knots are no doubt caused while the fiber is still in the growing plant, by an unequal cell pressure.

The structure of bast fibers may also be shown by treatment with a reagent recommended by Haller (*Textile Forschung*, 1920, p. 22). The bast fibers are immersed for several hours in an acidified 10 percent solution of stannous chloride, well washed, and treated with a 10 percent solution of gold chloride. The separating surfaces between the fiber cells become brownish red in color and the structure may be easily seen. This reaction may be employed in connection with fibers of jute, hemp, flax, and typha.

There are several other methods that may be employed for exhibiting the structure of vegetable fibers. One that has been extensively employed is examination in polarised light after causing the fiber to swell by treatment with strong caustic soda solution. Nodder [1] also describes the following method: The fiber to be examined is mounted in a strong calcium chloride solution which has been tinted a pale yellowish brown color by the

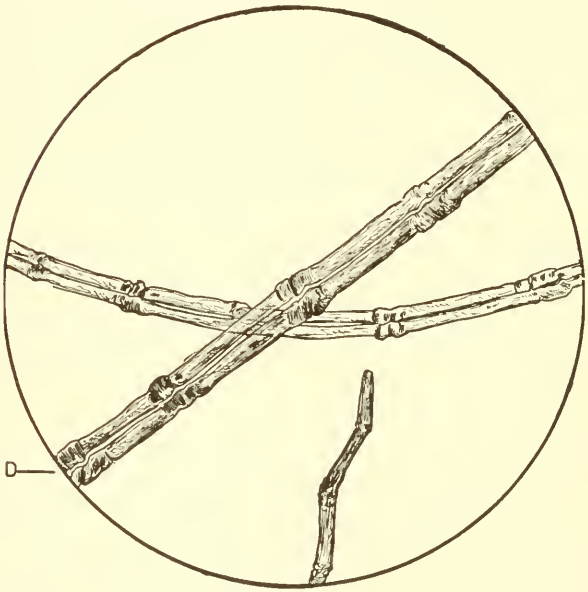


Fig. 150.

Fig. 151.

Fig. 150.—A Typical Bast Fiber (×350), Showing the Jointed Structure or Dislocations at *D*. (Micrograph by author.)

Fig. 151.—A Bundle of Bast Fibers. (×400.) (After Lecomte.)

addition of iodine. While the fiber is being examined under moderately low magnification, pressure is exerted on the cover glass, any lateral movement being carefully avoided. With care and practice the fiber may often be squeezed, without breaking the cover glass, until its width is increased as much as ten to fifteen times. The fibrillar structure will then be well displayed and the growth layers of the cell-wall will become

[1] *Jour. Text. Inst.*, 1922, p. 163.

widely separated and distinctly visible. The non-visibility of the fibrils under ordinary microscopic examination is presumably due to the fact that they are so close together as to be beyond the resolving power of the microscope, but by distending the fiber in the manner described the separate fibrils are brought within the limits of visibility. The dimensions of the fibrils in flax, as they exist in the uncompressed fiber, are estimated to be about 0.00003 mm., that is to say there are about 1000 of these fibrils across the width of the fiber. When linen is treated in the manner above described by Nodder the fibrils are seen to form left-handed spirals, and the same is also true with ramie; with hemp, however, the fibrils always form right-handed spirals, as does also jute. Cotton also exhibits a distinct fibrillar structure, but shows both right-handed and left-handed spirals in different parts of the same fiber.

Bast fibers are the long, tough cells found in the barks and stems of various plants. The cell-walls of these fibers are usually partially changed from pure cellulose into lignin and are thickened. There is usually a considerable amount of foreign matter also contained in the cell-wall, and often this becomes sufficiently characteristic to serve as a means of identifying the various fibers by the application of chemical reagents. Fibers which contain only pure cellulose are colored blue when treated with the iodine-sulfuric acid reagent, while fibers containing lignin are colored yellow to brown by the same test. The most satisfactory test for lignification is that given by Maule [1] as follows: Sections are soaked for about five minutes in a 1 percent solution of potassium permanganate, and after washing in water, are soaked for two to three minutes in dilute hydrochloric acid, and finally in ammonia. All lignified parts assume a red color by this treatment.

3. Dimensions of Fiber Cells.—Unlike seed-hairs, the individual cells of bast fibers are not of sufficient length for use in spinning, but as they are held together with considerable firmness to form bundles of great length, they are utilised in this form.

Owing to the difference in the length of the commercial fiber elements between seed-hairs and bast fibers, there are very material differences in the methods of spinning these fibers into yarns and the character of the machinery required therefor. Cotton cards and spinning frames, for example, which are adapted for the preparation and spinning of the relatively short cotton fibers, cannot be used for the processing of linen or ramie, hemp or jute, but specially designed machines for these fibers are required. Due to the composite nature of the bast fibers, the commercial length, even of the same general class, may vary within wide limits, and in the case of waste the fibers may be reduced to their ultimate elements.

[1] *Beitr. Wiss. Bot.*, 1900, vol. 4, p. 166.

Wiesner gives the following table showing the length of raw fibers and the dimensions of the cells composing them:

Fiber.	Length of Raw Fiber, Cm.	Length of Cells, Mm.	Breadth of Cells.		
			Min., Microns.	Max., Microns.	Aver., Microns.
Tillandsia fiber	2–22	0.2–0.5	6	15	
Esparto grass	10–40	1.5–1.9	9	15	
Cordia latifolia	50–90	0.1–1.6	14.7	16.8	15
Phormium tenax	80–110	2.5–5.6	8	29	13
Abelmoschus tetraphyllos	60–70	0.1–1.6	8	20	16
Bauhinia racemosa	50–150	1.5–4.0	8	20	
Jute (*Corchorus capsularis*)	150–300	0.8–4.1	10	21	16
Thespesia lampas	100–180	0.9–4.7	12	21	16
Urena sinuata	100–120	1.1–3.2	9	24	15
Sida retusa	80–100	0.8–2.3	15	25	
Calotropis gigantea (bast)	20–30	0.7–3.0	18	25	
Aloë perfoliata	40–50	1.3–3.7	15	24	
Flax (*Linum usitatissimum*)	20–140	2.0–4.0	12	25	16
Hemp (*Cannabis sativa*)	100–300	0.8–4.1	16	32	20
Jute (*Corchorus olitorius*)	150–300	0.8–4.1	16	32	20
Hibiscus cannabinus	40–90	4.0–12.0	20	41	
Sunn hemp (*Crotolaria juncea*)	20–50	0.5–6.9	20	42	
Bromelia karatas	100–110	1.4–6.7	27	42	
China grass (*Bœhmeria nivea*)	.....	22.0	40	80	50
Ramie (*Bœhmeria tenacissima*)	.....	8.0	16	12.6	
Cotton (*Gossypium barbadense*)	4.05	40.5	19.2	27.9	25.2
" (*G. conglomeratum*)	3.51	35.1	17	27.1	25.9
" (*G. herbaceum*)	1.82	18.2	11.9	22	18.5
" (*G. acuminatum*)	2.84	28.4	20.1	29.9	29.4
" (*G. arboreum*)	2.50	25.0	20	37.8	29.9
Cotton wool (*Bombyx heptaphyllum*)	2–3	20–30	19	29	
Vegetable silk (*Calotropis gigantea*)	2–3	20–30	12	42	38
" (*Asclepias*)	.....	10–30	20	44	
" (*Marsdenia*)	.....	10–25	19	33	
" (*Strophantus*)	.....	10–56	49	92	
" (*Beaumontia*)	.....	30–45	33	50	
Linden-bast	.....	1.1–2.6	....	....	15
Sterculia villosa	.....	1.5–3.5	17	25	20
Holoptelea integrifolia	.....	0.9–2.1	9	14	12
Kydia calycina	.....	1–2	17	24	
Lasiosyphon speciosus	.....	0.4–5.1	8	29	
Sponia Wightii	.....	4	....	....	21
Pandanus odoratissimus	.....	1.0–4.2	....	....	20
Pita fiber	.....	1.0–2.2	16	21	17
Coir fiber	.....	0.4–0.9	12	20	16

Vétillard gives a somewhat similar table as follows:

Name.	Length, Mm.			Breadth, Microns.			Ratio of Breadth to Length.
	Min.	Max.	Mean.	Min.	Max.	Mean.	
Linen	4	66	25	15	37	20	1200
Hemp (*Cannabis sativa*)	5	55	20	16	50	22	1000
Hop fiber (*Humulus lupulus*)	4	19	10	12	26	16	620
Nettle fiber (*Urtica dioica*)	4	57	27	20	70	50	550
Ramie (*Urtica nivea*)	60	250	120	.....	80	50	2400
Fiber of paper mulberry	.....	25	10	.....	.....	30	350
Sunn hemp (*Crotalaria juncea*)	4	12	8	25	50	30	260
Broom-grass (*Sarothamnus vulgaris*)	2	9	5	10	25	15	330
Feather-grass (*Spartium junceum*)	5	16	10	.....	.....	20	500
White clover (*Melilotus alba*)	5	18	10	20	36	30	330
Cotton	10	40					
Gambo hemp (*Hibiscus cannabinus*)	2	6	5	14	33	21	240
Linden-bast (*Tilia europæa*)	1.2	5	2	14	20	16	125
Jute (*Corchorus capsularis*)	1.5	5	2	20	25	22.5	90
Lace bark (*Lagetta lintearia*)	3	6	5	10	20	.....	500
Willow (*Salix alba*)	.....	3	2	17	30	22	90
Esparto	0.5	3.5	1.5	7	18	12	125
Lygæum spartum	1.3	4.5	2.5	12	20	15	160
Pineapple fiber	3	9	5	4	8	6	830
Silk-grass (*Bromelia karatas*)	2.5	10	5	20	32	24	210
Wild pineapple (*Bromelia pinguin*)	0.8	2.5	2	8	16	13	150
New Zealand flax (*Phormium tenax*)	5	15	9	10	20	16	550
Yucca fiber	0.5	6	4	10	20	15	170
Sansevieria fiber	1.5	6	3	15	26	20	150
Pita (*Agave americana*)	1.5	4	2.5	20	32	24	100
Manila hemp (*Musa textilis*)	3	12	6	16	32	24	250
Banana (*Musa paradisaica*)	.....	.....	5	20	40	28	180
Date palm (*Phœnix dactylifera*)	2	6	3	16	24	20	150
Talipot palm (*Corypha umbraculifera*)	1.5	5	3	16	28	24	120
Oil palm (*Elæis guineensis*)	1.5	3.5	2.5	10	13	11	230
Raphia tædigera	1.5	3	2.5	12	20	16	160
Ita palm (*Mauritia flexuosa*)	1	3	1.5	10	16	12	130
Coir fiber (*Cocos nucifera*)	0.4	1	0.7	12	24	20	35

The comparative sizes of the fiber elements are very variable, therefore the figures in the last column of the above table should be used as the most distinctive characteristic. Many conditions of growth and cultivation cause the fiber elements to be longer or shorter, thicker or thinner; also in the case of bast fibers their position in the plant stalk introduces differences in dimensions. From these considerations it follows that the

relative values for the sizes of fiber elements can only be used with proper circumspection and they have no positive significance.

4. Classification.—Perhaps the most systematic and complete enumeration of the various vegetable fibers, together with a classification of their technical uses, is that given by Dodge, from which the following abstract is taken:

STRUCTURAL CLASSIFICATION

A. Fibrovascular Structure.

1. *Bast Fibers.*—Derived from the inner fibrous bark of dicotyledonous plants or exogens, or outside growers. They are composed of bast-cells, the ends of which overlap each other, so as to form in mass a filament. They occupy the phloëm portion of the fibrovascular bundles, and their utility in nature is to give strength and flexibility to the tissue.

2. *Woody Fibers.*

(*a*) The stems and twigs of exogenous plants, simply stripped of their bark and used entire, or separated into withes for weaving or plaiting into basketry.

(*b*) The entire or subdivided roots of exogenous plants, to be employed for the same purpose, or as tie material, or as very coarse thread for stitching or binding.

(*c*) The wood of exogenous trees easily divisible into layers or splints for the same purposes, or more finely divided into thread-like shavings for packing material.

(*d*) The wood of certain soft species of exogenous trees, after grinding and converting by chemical means into wood-pulp, which is simple cellulose, and similar woods more carefully prepared for the manufacture of artificial silk.

3. *Structural Fibers.*

(*a*) Derived from the structural system of the stalks, leaf-stems, and leaves, or other parts of monocotyledonous plants, or inside growers, occurring as isolated fibrovascular bundles, and surrounded by a pithy, spongy, corky, or often a soft, succulent, cellular mass covered with a thick epidermis. They give to the plant rigidity and toughness, thus enabling it to resist injury from the elements, and they also serve as water-vessels.

(*b*) The whole stems, or roots, or leaves, or split and shredded leaves of monocotyledonous plants.

(*c*) The fibrous portion of the leaves or fruits of certain exogenous plants when deprived of their epidermis and soft cellular tissue.

B. Simple Cellular Structure.

4. *Surface Fibers.*

(*a*) The down or hairs surrounding the seeds, or seed envelopes, or exogenous plants, which are usually contained in a husk, pod, or capsule.

(*b*) Hair-like growths, or tomentum, found on the surfaces of stems and leaves, or on the leaf-buds of both divisions of plants.

(*c*) The fibrous material produced in the form of epidermal strips from the leaves of certain endogenous species, as the palms.

5. *Pseudo-fibers, or False Fibrous Material.*

(*a*) Certain of the mosses, as the species of the *Sphagnum*, for packing material.

(*b*) Certain leaves and marine weeds, the dried substance of which forms a more delicate packing material.

(*c*) Seaweeds wrought into lines and cordage.

(*d*) Fungus growths, or the mycelium of certain fungi that may be applied to economic uses, for which some of the true fibers are employed.

The bast fibers are clearly defined, and all such fibers when simply stripped are similar in form as to outward appearance, differing chiefly in color, fineness, and strength. An example of a fine bast fiber is the ribbons or filaments of hemp. The woody fibers are only fibrous in the broad sense, as their cellulose filaments are very short and are easily separated and all extraneous matter removed by chemical means, as for the manufacture of paper-pulp or of artificial silk. The greater number of woody fibers are merely wood in the form of flexible slender twigs or osiers that are useful for making baskets; or the larger branches may be split or subdivided into strips, withes, or flat ribbons of wood for making coarser baskets. The softer woods still further divided give the product known as " excelsior," which can only claim a place in the list of fibers on account of its use in upholstery or packing. The structural fibers are found in many forms differing widely from each other, and the surface fibers are still more varied in form.[1]

Among the many forms of the structural fibers may be enumerated the following: The stiff, white, or yellowish fibers forming the structure of all fleshy-leaved or aloelike plants, as the century plant, the yuccas, agave, and pineapple, or the fleshy trunk of the banana; the coarser bundles of stiff, fibrous substance which gives strength to the trunks, leaf, stem, and even the leaves of palms, such as piassave, derived from the dilated margins of the petioles of a palm; stiff fibers extracted by maceration from the bases of the leaf-stems of the cabbage palmetto, or the shredded leaves of the African fan palm, known as *Crin végétal*, rattan strips and fibrous material derived from bamboo, the corn-stalk, broom-corn, and from reeds, sedges, and grasses; still other forms are the coir fiber surrounding the fruit of the cocoanut, the fiber from pine-needles, and the fibrous mass filling the sponge cucumber, which is a peculiar example of a structural fiber derived from an exogenous plant. Surface fibers may consist of the

[1] The following table shows the imports into the United States of various raw vegetable fibers for the year ending June 30, 1912:

	Pounds.	Value.
Cotton	109,780,071	$20,217,581
Flax	21,800,000	3,778,501
Hemp	10,014,000	1,100,273
Istle	19,670,000	776,351
Jute	202,002,000	7,183,385
Kapok	4,198,000	570,084
Manila hemp	137,072,000	8,000,865
New Zealand flax	10,728,000	483,310
Sisal grass	228,934,000	11,866,843
All other	18,540,000	703,254
Total	762,738,071	$54,680,447

elongated hairs such as surround the pods of the thistle, and known as thistle-down, or they may be fibrous growths around seed clusters, as the cotton-boll, the milk-weed pod, etc., or they may be the leaf scales or tomentum found on the under surface of leaves or epidermal strips of palm leaves, such as raffia.

Dewey [1] gives the following economic classification of the vegetable fibers:

(1) The cottons, with soft, lint-like fiber $\frac{1}{2}$ in. to 2 ins. long, composed of single cells, borne on the seeds of different species of cotton-plants.

(2) The soft fibers, or bast fibers, including flax, hemp, and jute; flexible fibers of soft texture, 10 to 100 ins. in length, composed of many overlapping cells and contained in the inner bark of the plants.

(3) The hard, or leaf, fibers, including Manila, sisal, Mauritius, New Zealand fibers, and istle, all having rather stiff, woody fibers 1 to 10 ft. long, composed of numerous cells in bundles, borne in the tissues of the leaf or leaf-stem.

ECONOMIC CLASSIFICATION

A. Spinning Fibers.

1. *Fabric Fibers.*

(*a*) Fibers of the first rank for spinning and weaving into fine and coarse textures for wearing apparel, domestic use, or house-furnishing and decoration, and for awnings, sails, etc. (The commercial forms are cotton, flax, ramie, hemp, pineapple, and New Zealand flax.)

(*b*) Fibers of the second rank, used for burlap or gunny, cotton bagging, woven mattings, floor-coverings, and other coarse uses. (Commercial examples are coir and jute.)

2. *Netting Fibers.*

(*a*) Lace fibers, which are cotton, flax, ramie, agave, etc.

(*b*) Coarse netting fibers, for all forms of nets, and for hammocks. (Commercial forms: Cotton, flax, ramie, New Zealand flax, agave, etc.)

3. *Cordage Fibers.*

(*a*) Fine-spun threads and yarns other than for weaving; cords, lines, and twines. (All of the commercial fabric fibers, sunn, Mauritius, and bowstring hemps. New Zealand flax, coir, Manila, sisal hemps, pandanus; [2] the fish-lines made from seaweeds.)

(*b*) Ropes and cables. (Chiefly common hemp, sisal, and Manila hemps, when produced commercially.)

B. Tie Material (*rough twisted*).

Very coarse material, such as stripped palm-leaves, the peeled bark of trees, and other coarse growths used without preparation.

[1] *Year-Book*, Dept. Agric., 1903.

[2] The pandanus fiber is obtained from the leaves of the *Pandanus odoratissimus*. Under the microscope can be recognised fiber elements, vascular tissue, and a small celled parenchym with single crystals of calcium oxalate. The fibers are 1–4 mm. long and have numerous variant forms. They are slender, up to 20 microns in breadth. The thickness is very uneven, so that when viewed lengthwise, the fiber appears thin in some places and thick in others (Höhnel).

C. Natural Textures.

1. *Tree-basts, with Tough Interlacing Fibers.*

(*a*) Substitutes for cloth, prepared by simple stripping and pounding. Cloth of this character has long been used by the natives of the Pacific Islands under the name of *Tappa* or *Kapa*. Other forms, such as the *Damajagua*, of Ecuador, are used in South America as cloth.

(*b*) Lace-barks, used for cravats, frills, ruffles, etc., and for whips and thongs. The lace-bark tree is the *Lagetta lintearia*, and grows principally in Jamaica. The fiber (or rather fabric) is obtained from the inner bark, occurring in concentric layers which are easily detachable, and which are suited to the most delicate textiles; when stretched out they form a pentagonal or hexagonal mesh very closely resembling lace (Fig. 152).

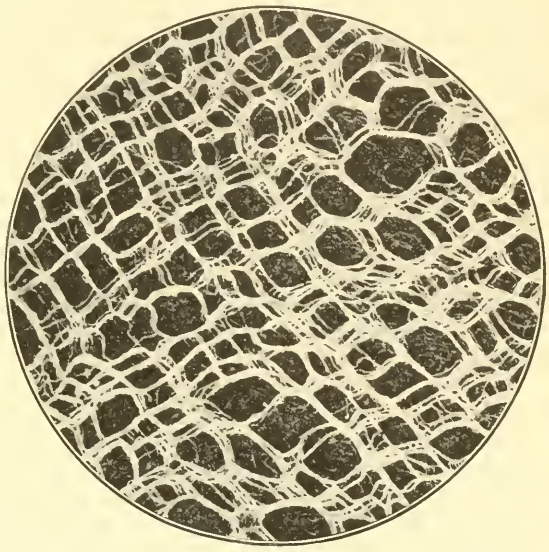


Fig. 152.—Lace Bark. (Herzog.)

2. *The Ribbon or Layer Basts*, extracted in thin, smooth-surfaced, flexible strips or sheets. (Cuba bast used as millinery material, cigarette wrappers, etc.) The Cuba bast here referred to is the lace-like inner bark from the *Hibiscus elatus*, which was formerly largely used for tying up bundles of Havana cigars. The plant also yields a bast fiber which is coarse but very strong, and is suitable for the making of cordage and coffee bags.

3. *Interlacing Structural Fiber or Sheaths.*

(*a*) Pertaining to leaves and leaf-stems of palms, such as the fibrous sheaths found at the bases of the leaf-stalks of the cocoanut.

(*b*) Pertaining to flower-buds. The natural caps or hats derived from several species of palms.

D. Brush Fibers.

1. *Brushes Manufactured from Prepared Fiber.*

(*a*) For soft brushes. (Substitutes for animal bristles, such as Tampico.)

(*b*) For hard brushes. (Examples: Palmetto fiber, palmyra, kittul, etc.) Kittul, or kitool, fiber is obtained from the jaggery palm, *Caryota urens*. The structural fiber is brownish black in color and lustrous, the filaments being straight and smooth. It somewhat resembles horsehair and curls like coir when drawn between the thumb and nail of the forefinger. In Ceylon the fiber is used for the manufacture of ropes of great strength which are used for tying elephants. It is largely used for making brushes of various kinds, especially machine brushes for polishing linen and cotton yarns, and for brushing velvets.

2. *Brooms and Whisks.*

(*a*) Grass-like fibers. (Examples: Broom-root, broom-corn,[1] etc.)

(*b*) Bass fibers. (Monkey bass, etc.)

3. *Very Coarse Brushes and Brooms.*

Material used in street-cleaning. Usually twigs and splints.

E. Plaiting and Rough-weaving Fibers.

1. *Used in Hats, Sandals, etc.*

(*a*) Straw plaits. From wheat, rye, barley, and rice straw. (Tuscan and Japanese braids.)

(*b*) Plaits from split leaves, chiefly palms and allied forms of vegetation. (Panama hats.) The true panama fiber for the making of the hats that go by that name is obtained from the *Planta de Torquilla* or *Carludovica Palmata*, which grows wild in the swamps of tropical America. The leaves employed for the making of the hats are the young ones, which are plucked before they have fully expanded. They are then boiled in water to which a little lemon juice has been added, and afterwards they are hung up to dry in an airy though shady place. Throughout the operations of drying and hat plaiting the straw should never be exposed to the sun, as this would cause the hat to have a streaky appearance owing to the unequal bleaching of the strips. When the leaves are nearly dry they are split into very narrow strips of an even width, and are then tied in bunches and left to dry. After the plaiting is finished the hats are cleaned with soap and lemon juice, polished, and are then ready for the market.

(*c*) Plaits from various materials. (Bast and thin woods used in millinery trimmings.)

2. *Mats and Mattings; also Thatch Materials.*

(*a*) Commercial mattings from Eastern countries. The Japanese floor mattings imported into this country are made either from the rush known as *Juncus effusus* (the Bingo-i mat rush), or from the *Cyperus unitans* (the Shichito-i mat rush), the better quality being made from the first-named product. The *Juncus effusus* is also grown on the Pacific Coast of the United States, as well as a similar species known as *J. robustus*.

(*b*) Sleeping-mats, screens, etc.

(*c*) Thatch-roofs, made from tree-basts, palm-leaves, grasses, etc.

3. *Basketry.*

(*a*) Manufactures from woody fiber.

[1] The fiber from broom-grass (*Sarothamnus vulgaris*) is a rather useful one for paper-making. According to Vétillard, it shows the following microscopic characteristics: The bast fibers are 2–9 mm. (mostly 5–6 mm.) long and 10–25 microns (mostly 15 microns broad). The ratio of length to breadth averages 330. The fibers are colored blue with iodine and sulfuric acid, or violet or yellowish; they are short, striped, full, and round, of small and very uniform diameter. The lumen looks like a line. The median layer, which is colored yellow, often stretches not beyond the point of the fiber, which is mostly rounded off, lapped over or forked. The sections lie in a thick network of median layer, and are small and blue (with iodine and sulfuric acid). Two different kinds of sections can be distinguished. The one has a lumen like a small point or short streak with or without any contents (yellow, granular), is polygonal, sharp-edged, with visible stratification, although not numerous yet readily seen; the outer layers are often somewhat lignified. The other sections, as with hemp, are irregular, but smaller, and are not colored as dark as the other ones; the lumen is line-shaped or open, often having some contents.

(*b*) From whole or split leaves or stems.

4. *Miscellaneous Manufactures.*

Willow-ware in various forms; chair-bottoms, etc., from splints or rushes.

F. Various Forms of Filling.

1. *Stuffing or Upholstery.*

(*a*) Wadding, batting, etc., usually commercially prepared lint-cotton.

(*b*) Feather substitutes for filling cushions, etc.; cotton, seed-hairs, tomentum from surfaces of leaves, other soft fibrous material.

(*c*) Mattress and furniture filling; the tow or waste of prepared fiber; unprepared bast, straw, and grasses; Spanish moss, etc.

2. *Caulking.*

(*a*) Filling the seams in vessels, etc.; oakum from various fibers.

(*b*) Filling the seams in casks, etc.; leaves of reeds and giant grasses.

3. *Stiffening.*

In the manufacture of "staff" for building purposes, and as substitutes for cow-hair in plaster; New Zealand flax; palmetto fiber.

4. *Packing.*

(*a*) In bulkheads, etc.; coir, cellulose of corn-pith. In machinery, as in valves of steam-engines; various soft fibers.

(*b*) For protection in transportation; various fibers and soft grasses; marine weeds; excelsior.

G. Paper Material.

1. *Textile Papers.*

(*a*) The spinning fibers in the raw state; the secondary qualities or waste from spinning-mills, which may be used for paper-stock, including tow, jute-butts, Manila rope, etc.

(*b*) Cotton or flax fiber that has previously been spun and woven, but which, as rags, finds use as a paper material.

2. *Bast Papers.*

This includes Japanese papers from soft basts, such as the paper mulberry.[1]

[1] The fiber of the *Broussonetia* (*Morus*) *papyrifera* is used in China and Japan for the making of paper and the preparation of fabrics, and in Europe for the manufacture of strong papers. Hence it is frequently to be found in such. According to Höhnel, the fibers employed for paper are very long, generally 6–15 mm. and up to 25 mm. even, and at the same time only 25–35 microns thick. Two kinds of fibers may be distinguished microscopically, thick and thin. They are partly thick-walled, smooth or marked, with very pronounced joints, and often partly ribbon-like and flat. The lumen at first on viewing the fiber lengthwise, is difficult to see, and usually contains here and there, near the point, some yellowish substance. In the ribbon-like fibers the ends are broad and rounded-off; the thick-walled fibers have narrower points sometimes sharp. The cross-sections of the fiber bundles is also naturally of two kinds. The one consists of a few very thick-walled sections, polygonal in form with blunt edges or inturning angles, and a rounded-off contour. The other is very large, and at the same time, consists of a collection of many single sections of small size, and with a rounded-off or irregular form. All sections show the pure cellulose fiber enclosed in a yellowish median layer of network, which only adheres slightly in single sections; hence single meshes are often free. The cross-sections, when removed from the network of median layer, are very similar to those of cotton, but possess a fine stratified structure, which is completely lacking in cotton. The sections often show

3. *Palm Papers.*

From the fibrous material of palms and similar plants. Palmetto and yucca papers.

4. *Bamboo and Grass Papers.*

This includes all paper material from grass-like plants, including the bamboos, esparto, etc.

5. *Wood-pulp, or Cellulose.*

The wood of spruce, poplar, and similar "paper-pulp" woods prepared by various chemical and mechanical processes.

Wiesner gives the following botanical classification of the more important vegetable fibers:

A. Vegetable Hairs.

1. Cotton (seed-hairs of *Gossypium* sp.).
2. Bombax cotton (fruit-hairs of *Bombaceæ*).
3. Vegetable silks (seed-hairs of various *Asclepiadaceæ* and *Apocynaceæ*).

B. Bast Fibers from the Stalks and Stems of Dicotyledonous Plants.

(*a*) *Flax-like fibers.*

4. Flax (*Linum usitatissimum*).
5. Hemp (*Cannabis sativa*).
6. Gambo hemp (*Hibiscus cannabinus*).
7. Sunn hemp (*Crotalaria juncea*).
8. Queensland hemp (*Sida retusa*).
9. Yercum fiber (*Calotropis gigantea*).

(*b*) *Bœhmeria fibers.*

10. Ramie or China grass (*Bœhmeria nivea*).

(*c*) *Jute-like fibers.*

11. Jute (*Corchorus capsularis* and *C. olitorius*).
12. Raibhenda (*Abelmoschus tetraphyllos*).
13. Pseudo-jute (*Urena sinuata.*)

(*d*) *Coarse bast fibers.*

14. Bast fibers from *Bauhinia racemosa.* The *Bauhinia* is a genus of arborescent or climbing plants found in tropical countries. The fiber is obtained from the bast of the inner bark, and may be made into coarse cordage, but it soon rots in water. The fiber is reddish in color and tough and strong, and has been employed in India for construction of bridges.
15. Bast fibers from *Thespesia lampas.*
16. Bast fibers from *Cordia latifolia.*

(*e*) *Basts.*

17. Linden bast [1] (*Tilia* sp.).

portions of the inner contents. The fibers often have adhering prismatic crystals of calcium oxalate. Lengthwise the fibers often appear to be enclosed by a thin-walled loose sheath.

[1] The fibers of linden bast are completely lignified. They are 1–5 mm. (mostly 2 mm.) in length and 14–20 microns (mostly 16 microns) in breadth. The ratio of the length to the breadth is about 125. Viewed longitudinally, the fiber appears very short, thin, stiff, and full. The points are sharp or irregular. Most of the small sections are polygonal with straight sides and pointed edges, and are firmly bound together into groups by a median layer which gives a dark yellow color when treated with iodine and sulfuric acid. The lumen is seen as a point, or layer.

18. Bast from *Sterculia villosa*.
19. Bast from *Holoptelea integrifolia*.
20. Bast from *Kydia calycina*.
21. Bast from *Lasiosyphon speciosus*.
22. Bast from *Sponia Wightii*.

C. Vascular Bundles from Monocotyledonous Plants.

(*a*) *Leaf fibers*.

23. Manila hemp (*Musa textilis* and others of this kind).
24. Pita (*Agave americana* and *A. mexicana*).
25. Sisal (*Agave rigida*).
26. Mauritius hemp (*Agave fœtida*).
27. New Zealand flax (*Phormium tenax*).
28. Aloe fibers (*Aloë* sp.).
29. Bromelia fibers (*Bromelia* sp.).
30. Pandanus fibers (*Pandanus* sp.).
31. Sansevieria fibers (*Sansevieria* sp.).
32. Sparto fibers (*Stipa tenacissima*).
33. Piassave (*Attalea funifera, Raphia vinifera*, etc.). Piassave fiber is obtained from a palm-tree, *Attalea funifera*. It is a structural fiber obtained from the dilated base of the leaf-stalks. It is stiff, wiry, and bright chocolate in color, and is principally used in the manufacture of brushes. It is also used on the street-sweeping machines in London. The palm grows principally in Brazil, where the natives use the fiber for making coarse cables which are very durable and so light that they will float on water.

(*b*) *Stem fibers*.

34. Tillandsia fibers, southern moss (*Tillandsia usneoides*).

(*c*) *Fruit fibers*.

35. Coir or cocoanut fiber (*Cocos nucifera*).
36. Peat fibers.

(*d*) *Paper fibers*.

37. Straw fibers (rye, wheat, oat, rice).
38. Esparto fibers (leaf fibers of *Stipa tenacissima*).
39. Bamboo fibers (*Bambusa* sp.).
40. Wood fiber (pine, fir, aspen, etc.).
41. Bast fiber from paper mulberry (*Broussonetia papyrifera*).
42. Bast fiber from *Edgeworthia papyrifera*.
43. Peat fibers.

Lecomte (*Textiles végétaux*) gives the following classification with reference to the botany of the textile fibers.

A. Vegetable Hairs.

Cotton.
Asclepias.
Calotropis.
Epilobium.
Typha, etc.
} Minor vegetable hair fibers.

B. Bast Fibers.

I. Dicotyledons.
- *a. Urticaceæ* family.
  - Hemp (*Cannabis*).
  - Ramie (*Bœhmeria*).
  - Nettle (*Urtica*).
  - Paper mulberry (*Broussonetia*).
  - Hop [1] (*Humulus*).
- *b. Linaceæ* family.
  - Linen (*Linum*).
- *c. Thymeleaceæ* family.
  - Lace bark (*Lagetta*).
  - Nepal paper (*Daphne*).
- *d. Tiliaceæ* family.
  - Jute (*Corchorus*).
  - Linden (*Tilia*).
- *e. Malvaceæ* family.[2]
  - Queensland hemp (*Sida*).
  - Cæsar weed (*Urena*).
  - Pseudo-hemps (*Hibiscus*).
- *f. Papilionaceæ* family.
  - Sunn hemp (*Crotalaria*).
  - Clover (*Melilotus*).
  - Ginestra (*Genista*).
  - Spanish sparto (*Spartium*).
- *g. Cordiaceæ* family.
  - *Cordia* fibers.
- *h. Asclepiadaceæ* family.
  - Giant asclepias (*Calotropis*).

[1] The hop fiber, which possesses an increasing importance in paper making, according to Höhnel, consists of elements from 4 to 19 mm. (mostly 10 mm.) long, and 12 to 26 microns (mostly 16 microns) broad. The bast fibers consist of pure cellulose. They are uniformly thick, and show two kinds of forms: thin, very thick-walled fibers with a line-like lumen, which is only noticeable when it contains some matter inside, and with long, tapering, sharp points; also flat, ribbon-like fibers with broad, rounded-off points and large lumen. In cross-section, the delicate net-work of median layer is especially noticeable, in the yellow meshes of which the blue, small cross-sections (which are very uniform in their dimensions) are loosely enclosed. Also isolated meshes are sometimes empty. The form of the cross-section has some similarity to that of hemp, but the lumena are almost always open and filled with a yellowish granular substance. Also the stratifications in the walls are less numerous and more difficult to observe.

[2] A rather remarkable fiber from the Malvaceæ family is that from *Adansonia digitata*, or Monkey Bread Tree, of Africa. The plant is one of the largest trees in the world and is also said to be one of the longest lived. It abounds in Africa from Senegal to Abyssinia. The fiber is derived from the bark and is strong and much valued for cordage. In Africa it is much used for rope, twine and sacking, and in India it is used for making elephant saddles. It has also been used in England for the manufacture of special kinds of paper.

II. Monocotyledons.
- *a. Gramineæ* family.
  - Sparto grass [1] (*Stipa*).
  - Weeping sylvan (*Lygeum*).
- *b. Liliaceæ* family.
  - New Zealand hemp (*Phormium*).
  - Yucca (*Yucca* sp.).
  - Bowstring hemps (*Sansevieria*).
- *c. Amaryllidaceæ* family.
  - Sisal hemps (*Agave*).
- *d. Bromeliaceæ* family.
  - Pineapple (*Ananas*).
  - Bromelia fibers (*Bromelia*).
- *e. Musaceæ* family.
  - Manila hemp (*Musa*).
- *f. Naiadaceæ* family.
  - Sea-wrack (*Zostera*).
- *g. Palmæ* family.
  - Coir (*Cocos*).
  - Raffia (*Raphia*).
  - Murumuru palm (*Astrocaryum*).
  - *Crin végétal* (*Chamærops*).
  - Rattan cane (*Calamus*).
  - Sago-palm (*Arenga*).
  - Date-palm (*Phœnix*).
  - Talipot palm (*Corypha*).
  - Oil-palm (*Elæis*).

5. Physical Structure of Seed-hairs.—The seed-hairs or plumose fibers, are divided into three morphological classes:

(1) Those consisting of single cells, one end of which is closed and tapers to a point, the other end being broken off abruptly where it is torn from the seed to which it was fastened during growth. This class includes

[1] The fibers obtained from the leaves of both the grasses *Stipa tenacissima* and *Ligacium Spartum* are known as Alfa fiber; it is also known by the name Esparto. It is especially employed in paper. The fibers of *Stipa tenacissima* are 0.5 to 3.5 mm. long and 7 to 18 microns broad. Those of *Lagacium Spartum* have a length of 1.3 to 4.5 mm. and a breadth of 12 to 20 microns. When viewed lengthwise both fibers are short, thin, full, lustrous, and of very uniform diameter. The lumen is seen as a fine line, and often contains a yellowish substance. The ends are tapering, and either somewhat rounded off or cut off obliquely. Most of the fibers are not lignified, although many are colored yellow with iodine and sulfuric acid. The cross-sections treated with these reagents appear partly yellow and partly blue. The innermost layers of the wall are nearly always unlignified, and on the other hand, the outer layers are always lignified. The form of the cross-sections is rounded. Apart from the fiber itself, in its microscopical examination, the web of cuticle is especially prominent. This consists of epidermal cells, fissure cells, and hairs, the last often being bent in the form of a hook. The web of cuticle has toothed side walls which are very remarkable. They are strongly silicified, and the silicious skeletons are easily recognised in the ash.

the most important plumose fibers, such as cotton and the vegetable silks.

(2) Those consisting of a series of cells joined together to form a continuous fiber; this class includes the tomentum or epidermal hair obtained from certain ferns; these are practically valueless as textile materials, though employed for upholstery and similar uses.

(3) Those consisting of several series of cells, represented by the fibers of the so-called *cotton-grass* and *elephant-grass*.

The hair fibers may originate on almost any organ of the plant exposed to the air. The following table indicates the origin of the majority of such fibers:

HAIR FIBERS

(1) Covering the seeds, either entirely or in part·
Cotton . . . . . *Malvaceæ*.
Marsdenia, *Calotropis*, *Asclepias*, *Vincetoxicum* } *Asclepideæ*.
Beaumontia, *Strophantus* } *Apocyneæ*.
Epilobium . . . *Œnotheraceæ*.
(2) Contained in the flower (rudimentary floral envelope):
Typha . . . . . *Typhaceæ*.
Eriophorum . . . . *Cyperaceæ*.
(3) Lining the interior of the fruit:
Ochroma, *Bombax*, *Eriodendron* } *Bombaceæ*.
(4) Covering stalks and leaves:
Cibotium . . . . . Ferns.

The cell-wall of the plumose fibers in some cases is relatively thin, while in others it is comparatively thick. It is generally without apparent structure, though sometimes it is seen to contain pores, and occasionally a meshlike interlacing of filaments is observable, especially at the base of the fiber. The inner surface of the cell-wall is usually coated with a cuticle of dried protoplasm, which is evidently similar in constitution to the outer cuticle, as it also remains undissolved when the fiber is dissolved in either concentrated sulfuric acid or an ammoniacal solution of copper oxide. Lecomte gives the following classification of vegetable fibers with respect to their cellular structure:

1. *Fiber consisting of a single isolated cell:* Cotton; *Asclepias* silk; *Bombax* cotton.
2. *Single fibers associated in bundles:* Unbleached jute; Linen (poorly prepared linen frequently contains parenchymous cells and epidermal cells); Ambari hemp (*Hibiscus*); Ramie; Hemp (well prepared).

3. *Fibers with medullary cells:* Queensland hemp (*Sida retusa*); *Cordia latifolia; Thespesia lampas.*
4. *Fibers with parenchymous cells: Abelmoschus tetraphyllos; Urena sinuata;* Sunn hemp (*Crotalaria juncea*); *Calotropis gigantea;* Hemp (as often prepared).

6. Physical Structure of Bast Fibers.—The general term of bast fiber includes really two distinct forms; if the fiber occurs in the bast itself it should be designated as true *bast fiber,* such as linen, hemp, and jute. When, however, the fibers do not occur in the bast, but in single bundles in the leaf structure of the plant, they should be designated as *sclerenchymous fibers.* In true bast fibers there are seldom to be noticed distinct pores, whereas the sclerenchymous fibers are abundantly supplied with them. On the other hand, however, the true bast fibers frequently show peculiar dislocations or joints caused by an unequal cell pressure in the growing plant; these are entirely absent in the sclerenchymous fibers. The ends of all bast fibers are usually quite characteristic and exhibit a wide diversity of forms; at times they are sharp-pointed and again blunt; some possess but a single point, while others are split or forked; sometimes the cell-wall is thicker than in the rest of the fiber, and sometimes it is thinner. When the cells occur in bundles they are frequently separated from one another by a so-called *median layer,* which forms a sort of matrix in which the separate filaments are imbedded. This layer usually differs in its chemical composition from the cell-wall proper, and gives different color reactions with various reagents, as it generally consists of lignified tissue. In many cases the well-walls appear to have a distinct structure, being composed of concentric layers which in cross-section exhibit a stratified appearance.

The bast fibers may be roughly divided into four classes with reference to the comparative sizes of the cell-wall and the inner canal or lumen:

(1) The canal takes up about four-fifths of the diameter of the fiber: Ramie and China-grass.
(2) The canal is about two-thirds of the diameter of the fiber: Pineapple fiber; Hemp; Pita and sunn hemp.
(3) The canal is mostly less than one-half the diameter of the fiber: Ambari hemp (*Hibiscus*); Yucca; New Zealand hemp (*Phormium tenax*); Manila hemp.
(4) The canal is often reduced to a mere line: Linen.

The inner canal is very regular (and consequently the cell-wall will be of uniform thickness) in fibers of yucca, New Zealand hemp, sunn hemp, pita hemp, linen, ramie, and the plumose fibers. On the other hand, the canal is irregular (with resulting irregularities in the thickness of the cell-wall) in fibers of jute, coir, *Urena sinuata, Abelmoschus,* etc.

All plant-cell membranes are doubly refractive toward light, and this is especially true of thick-walled cells which are parallel to the fiber proper.

If such a fiber is examined in the dark field of a micro-polariscope it shows a beautiful arrangement of bright prismatic colors.

The degree of double refraction varies with different fibers; in some, as for example in coir, it is very weak, while in others, such as linen and hemp, it is very strong. The following table gives the polarisation colors shown by various fibers:

Fiber.	Polarisation of Colors.
Vascular and parenchymous cells of wood and straw	Dark gray.
Epidermal cells of straw and esparto	Dark gray.
Coir	Dark gray.
Cotton	Dark gray to light gray; also white to yellow.
New Zealand flax	Ditto.
Fiber cells of jute and esparto	Dark gray to light gray; yellowish to red.
Bast cells of flax and hemp	White, yellowish, orange, red, violet, changing to yellowish white and violet.

It is difficult to formulate many sharp distinctions between the bast fibers, for, as a class, they exhibit many points of similarity. There is frequently to be observed, for example, almost as many divergences from a supposedly normal type among the individual fibers if any one kind as between the fibers of different kinds. That is to say, in a sample of linen, while the general appearance would indicate that the lumen or inner canal of the fiber was relatively narrow, yet in some of the fibers the lumen may appear quite broad; and in a sample of hemp where the general appearance of the lumen is quite broad, there may be a number of fibers exhibiting very narrow lumens. The same comments are also true of most of the other general characteristics of the bast fibers. The appearance and form of the ends of the cells may pass through all manner of variations from pointed to blunt or even forked in the same sample of any one of the bast fibers, so it is generally useless to draw any conclusions as to identity from the appearance of the fiber ends alone. The joint-like structure of some of the bast fibers offers a somewhat better means of discrimination, though even here it is not safe to make too broad generalisations. Linen fibers very frequently exhibit these joint marks, yet there may be found numerous linen fibers with no appearance of joints at all.

7. Microscopical Characteristics of Vegetable Fibers.—The following table gives the characteristics of the common vegetable fibers used in the textile and paper industries:

Fiber.	Individual Fibers.		Microscopical Appearance.	Color Reaction with		
	Length, Inches.	Diameter, Inches.		Zinc Chloriodide.	Phloroglucinol.	Aniline Sulfate.
Cotton	$1\frac{1}{2}$–$1\frac{3}{4}$ av. = 1	0.0047–0.0070 ac. = 0.0062	Appears as a flat, ribbon-like band, more or less twisted on its longitudinal axis. Twist of fiber not continuous in one direction; cell-walls thick; lumen breadth much thicker than cell-wall; between thickened edges fiber shows finely granulated surface. Diameter uniform for $\frac{3}{4}$ length, then tapers to a point where it is cylindrical and solid	Wine-red	Not colored	Not colored
Flax	$\frac{1}{5}$–$2\frac{3}{5}$ av. = $1\frac{1}{5}$	0.0030–0.0062 av. = 0.0040	Cylindrical tapering to sharp point; cell-wall so thick that lumen appears as thread; fine cross-lines at intervals give appearance of joints or nodes, sometimes intersecting like letter X	Purple to yellow	Slightly red or not colored	Slightly yellow or not colored
Hemp	$\frac{1}{20}$–$\frac{1}{4}$	0.0040–0.0080 av. = 0.0050	Lumen is broad, equaling or exceeding the thickness of the walls. Pronounced longitudinal striations. Ends of fibers blunt and thick-walled, often with lateral branches. Dislocations or folds; also swellings and cross-fissures. Fibers less transparent than flax and canal more difficult to distinguish	Purple to yellow	Slightly red	Yellowish green coloration
Jute	$\frac{1}{20}$–$\frac{1}{5}$	0.0025–0.0080 av. = 0.0045	Lumen irregular, at times as wide or wider than cell-wall; at ends of fiber lumen broadens out; end round. Longitudinal striations, no transverse markings, no jointed ridges	Yellow	Deep red	Slightly yellow

Fiber.	Individual Fibers.		Microscopical Appearance.	Color Reaction with		
	Length, Inches.	Diameter, Inches.		Zinc Chloriodide.	Phloroglucinol.	Aniline Sulfate.
Manila hemp	$\frac{1}{10}$–$\frac{1}{2}$ av. = $\frac{1}{4}$	0.0040–0.0080 av. = 0.0060	Lumen broad, distinct and uniform; cell-wall thin; ends narrow and sharp; no markings; diameter uniform	Uncooked, yellow; cooked, red		
Straw	$\frac{1}{250}$–$\frac{1}{20}$ av. = $\frac{1}{35}$		Bast cells are long thin fibers of regular structure with small canal; very slender and taper to fine point. Epidermal cells are thick-walled, short, broad, serrated. Parenchyma cells thin-walled and shaped like coffee bean	Blue to greenish	Colorless to red	Colorless to yellow
Esparto	$\frac{1}{50}$–$\frac{1}{10}$	0.0017–0.0045 av. = 0.0030	Cells smaller than, but very similar to, straw cellulose. Esparto does not have the thin-walled bean-shaped cells, but has very small characteristic pear-shaped cells. Bast cells have numerous cross-markings	Same as straw	Same as straw	Same as straw
Ramie	$\frac{1}{4}$–2.0 av. = 1.0	0.010–0.020 av. = 0.0125	Bast cells very long and broad, diameter very irregular; base very irregular; lumen, sometimes quite distinct, and sometimes disappearing entirely; fibers show numerous joints and transverse fissures; ends of fibers form a thick-walled, rounded point, and the lumen is reduced to a line	Dark red to greenish yellow	Colorless	Colorless

Fiber.	Individual Fibers.		Microscopical Appearance.	Color Reaction with		
	Length, Inches.	Diameter, Inches.		Zinc Chloriodide.	Phloroglucinol.	Aniline Sulfate.
New Zealand flax	$\frac{1}{10}-\frac{3}{5}$ av. $=\frac{1}{3}$	0.0020–0.0070 av. $=0.0040$	Fiber elements, or cells, are usually very regular and uniform, surface is smooth in general. Lumen is usually narrower than cell-wall and very uniform in width. Ends are sharply pointed, and not divided. Fragments of parenchyma and epidermis can often be seen on the fibers	Deep yellow or brownish	Reddish	Yellowish or greenish yellow
Manila hemp, sisal or Domingo hemp	$\frac{1}{10}-\frac{1}{4}$	0.0050–0.0085	Fibers usually very stiff, and become very broad toward middle; have broad lumen, broad, blunt, thick ends, which are seldom forked. Short thick-walled cells are abundant, and show a narrow lumen and distinct surface pores. Peculiar spiral and parenchyma cells are often present	Yellow	Red	Yellow
Pita fiber	$\frac{1}{10}-\frac{1}{5}$	0.0040–0.0080 av. $=0.0055$	Fiber is stiff and short, has a rather thin wall. Fiber has a distinctive wavy appearance and is very elastic. Very similar to sisal hemp in microscopical appearance	Yellow	Red	Yellow
Pineapple leaf fiber	$\frac{1}{10}-\frac{2}{5}$	0.0010–0.0020	Fiber very fine and has great durability. Lumen narrow and appears like a line. This fiber is distinguished from all other leaf fibers by its extreme fineness	Blue to greenish yellow	Colorless to light red	Colorless to yellow

Fiber.	Individual Fibers.		Microscopical Appearance.	Color Reaction with		
	Length, Inches.	Diameter, Inches.		Zinc Chlor-iodide.	Phloroglu-cinol.	Aniline Sulfate.
Coniferous wood fibers			Fibers from coniferous trees have a characteristic flat ribbon-like appearance, and numerous circular spots or pores are to be seen on many of them. The circular markings are more prominent in hard strong sulfites or sulfates, but are often less distinct in well-boiled pulps. Occasionally the cells are twisted something like cotton fibers. The shape and distribution of the pores in the fibers give some indication of the tree used	Blue	Colorless	Colorless
Broad-leaf hardwood fibers			The fibers from broad-leaf trees are shorter and more cylindrical in shape, and are always pointed at each end, and occasionally exhibit cross-markings. In addition to the true fibers, there are always a number of vessels, tubular in shape, short and of very large diameter, which show numerous pits; these establish the presence of fibers from broad-leaf trees	Dark blue	Colorless	Colorless

8. Physical Properties; Color.—The vegetable fibers in the raw state vary considerably in color; some, like cotton, ramie, and the vegetable silks, are almost pure white. Others, like linen, possess a grayish brown color; while still others, like jute and hemp, have a decided brown color. These colors, however, are due to incrusting impurities, as the cellulose fibers, purified and freed from all such foreign matters, are always white.

9. Luster.—The vegetable fibers are usually less lustrous than those of animal origin, and especially silk, though they differ much in this respect. Cotton probably has the least luster of any, as its surface is by no means smooth and even, but presents a wrinkled and creased appearance, hence scatters the rays of light reflected therefrom. Other plumose fibers, such as the various vegetable silks, have a very smooth surface, and consesequently exhibit considerable luster. Linen, jute, ramie, and the bast fibers in general, when separated into their fine filaments and properly freed from all incrusting matter, possess a rather high degree of luster, for though they have more or less roughened places and irregularities on their surface, the major portion of such surface is smooth and regular.

10. Elasticity.—The more closely the fiber approximates to pure cellulose the greater becomes its flexibility and elasticity, and the more it is lignified, that is to say, the more it is changed into woody tissue, the less these qualities become. That is to say, the highly lignified fibers are stiff and brittle and but little adapted to the spinning of fine yarns.

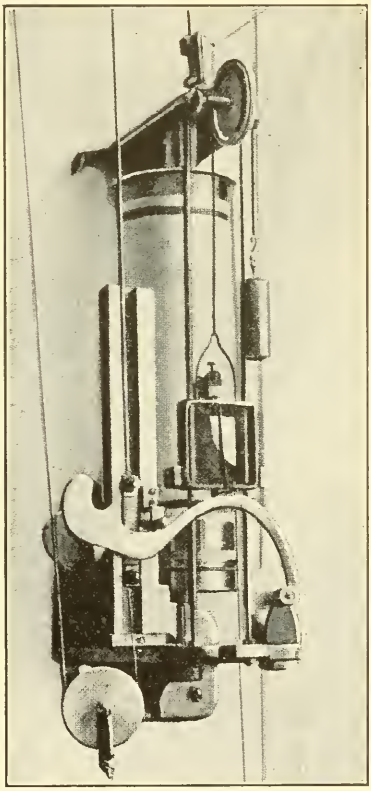


FIG. 153.—Apparatus for Testing the Elasticity of Yarns.

An apparatus for testing the elastic properties of yarns and automatically recording the load and stretch is described by J. A. Matthew[1] and is shown in Fig. 153. Matthew studied the relations of total and permanent stretch in various yarns and found an approximate constancy of the ratio of total stretch (Y_t) to permanent stretch (Y_p) in the case of flax yarns and hemp, but with both gray and bleached cotton the ratio was found to decrease as

[1] *Jour. Text. Inst.*, 1922, p. 45.

the breaking point was approached. The following table gives the mean values of these ratios:

VALUES OF Y_t/Y_p

Load Applied Before Unloading, Ounces.	Cotton 10's, American.		Flax 30's lea.			Hemp, 25's lea.
	Gray.	Bleached.	Green.	Boiled.	Bleached.	
2	1.6	1.81	1.72	....	1.53	
6	1.49	1.64	1.69	1.54	1.47	1.62
10	1.36	1.50	1.69	1.53	1.48	1.59
14	....	1.42	1.70	1.55	1.50	1.59
18	....	1.38	1.72	1.56	1.50	1.60
22	....	1.34	....	1.58	....	1.58
26	....	....	....	....	....	1.58
Average.....	....	....	1.7	1.55	1.5	1.59

11. Tensile Strength.—In tensile strength the vegetable fibers vary considerably; owing to the great difference in the physical form and thickness of the various fibers, it is difficult to give a comparison of their respective strengths. The following table gives a comparison between the more important fibers:

Fiber.	Breaking Length in Kilometers.	Tensile Strength, Kilograms per Square Millimeter.
Cotton	23.0	34.27
Linen	24.0	36.00
Jute	34.5	49.51
Hemp	52.0	78.00
Coir	17.8	
Manila hemp	31.8	
China-grass	20.0	
Raw silk	30.8	40.04

12. Hygroscopic Properties.—The hygroscopic moisture contained in vegetable fibers is considerably lower than that present in either wool or silk. While the latter fibers under normal atmospheric conditions will average as much as 12 to 16 percent of moisture, cotton, and linen will have only from 6 to 8 percent. The following table (after Wiesner) gives the amount of moisture in various vegetable fibers in the ordinary air-dry condition, and also the greatest amount they will absorb hygroscopically.

HYGROSCOPIC MOISTURE IN VEGETABLE FIBERS.

Fiber.	Air-dry Condition. Percent.	Maximum Amount Hygroscopic Water. Percent.
Cotton	6.66	20.99
Flax (Belgian)	5.70	13.90
Jute	6.00	23.30
China-grass	6.52	18.15
Manila hemp	12.50	50.00
Sunn hemp	5.31	10.87
Hibiscus cannabinus	7.38	14.61
Abelmoschus tetraphyllos	6.80	13.00
Esparto	6.95	13.32
Urena sinuata	7.02	15.20
Piassave	9.26	16.98
Sida retusa	7.49	17.11
Aloë perfoliata	6.95	18.03
Bromelia karatas	6.82	18.19
Thespesia lampas	10.83	18.19
Cordia latifolia	8.93	18.22
Bauhinia racemosa	7.84	19.12
Tillandsia fiber	9.00	20.50
Pita	12.30	30.00
Calotropis gigantea (bast)	5.67	13.13

According to Scheurer [1] each kind of fiber possesses a definite capacity of absorption when exposed to the action of steam under constant conditions. When equilibrium had become established he obtained the following results:

Fiber.	Percentage Moisture.
Cotton	23.0
Raw linen	27.7
Raw jute	28.4
Bleached silk	36.5
Bleached and mordanted wool	50.0

Höhnel has made some very interesting microscopical investigations on the effect of moisture on the dimensions of fibers; his results may be summarised as follows:

1. Every fiber becomes thicker on moistening with water, whether the fiber is twisted or not. Plant fibers differ from animal fibers in their behavior, in that they swell up more rapidly and to a greater degree. Animal fibers when moistened

[1] *Bull. Soc. Ind. Mulhouse*, 1900 p. 89

become 10 to 14 percent thicker; for instance, human hair 10.67 percent, angora wool 10.2 percent, white alpaca wool 13.7 percent, tussur silk 11 percent. Only those hairs which possess a large medulla swell to any extent, since the medullary cells are most strongly distended, for instance, cow-hair gives 16 percent. The thickening of plant fibers amounts generally to 20 percent or more. Thus New Zealand flax gave for three determinations 19.5, 20.0, and 22.3 percent; aloe hemp 25.8 percent, linen 17.1 percent, 29.0, 21.1 percent, hemp 21.1, 25.2, 21.0 percent, cotton 27.5 percent, etc.

2. A fiber may be either lengthened or shortened by moistening, or retain its original length. The same can also be brought about by drying. It all depends on the condition in which the fiber occurs, and this is governed by the treatment to which the fiber has been previously subjected.

3. The alteration in length in the case of vegetable fibers fluctuates between 0.05–0.10 percent, and with animal fibers between 0.50–1.00 percent.

4. If one and the same part of a thread is repeatedly moistened and dried, it gives the following results:

(*a*) A naturally untwisted fiber of flax, hemp, aloe, China-grass, cotton, and Manila hemp become lengthened on moistening and correspondingly shortened (namely 0.05–0.10 percent) on drying in the air.

(*b*) New Zealand flax of trade behaved itself in just the reverse manner.

(*c*) The majority of the vegetable fibers show the peculiarity of attaining the greatest length on moistening with the breadth, when they are wetted with water they are shortened about 0.01–0.03 percent. Therefore, when a wet fiber is dried, it at first becomes longer and then rapidly shortens.

(*d*) When a wet vegetable fiber is strongly stretched and is allowed to dry in this condition, it shows subsequently either (1) in case of wetting of or of drying an actual shortening of 0.05–0.10 percent (raw China-grass) or (2) there occurs at first a shortening (by wetting and drying), while later the fiber acts in a manner similar to New Zealand flax, consequently shortening itself on being moistened with the breadth; or finally (3) the fiber shortens itself at first, and then like an ordinary fiber, becomes lengthened (Manila hemp).

(*e*) All strongly twisted fibers show the peculiarity of lengthening on drying and shortening on wetting. In this case the actual shortening in the beginning is important.

(*f*) Any natural animal fiber is always lengthened by wetting and shortened by drying, both values being about 0.5–1.0 percent.

(*g*) Any single strongly twisted animal fiber at first shows a shortening of 1-2 percent, and then behaves just like an untwisted fiber, only the values are much less.

(*h*) A stretched dried animal fiber is shortened on being wet for the first time (generally about one percent), and subsequently behaves like one which had not been stretched.

It may be seen from these results of microscopic investigation that the behavior of the fibers on swelling in water is very remarkable and distinctive, and that in this particular very essential differences exist between vegetable and animal fibers.

This investigation helps to explain the fact why ropes shorten when left in water. Fibers which are not stretched or are only slightly so, are arranged in ropes in permanently fixed spirals. Since the fibers can only be lengthened but slightly, or not at all, while they are thickened 20–25 percent by swelling, the rope as well as the single twisted fibers must

become shortened. If the spiral fibers are very elastic, as is the case of the animal fibers which may be stretched 5 to 36 percent in the moist condition without breaking, then the cylinder composed of them will shorten but slightly on swelling (or even none at all), because the spirals are capable of being lengthened. Thus it has been observed that a hemp rope will shorten 8 to 10 percent, whereas a silk rope will shorten only 0.24 to 0.95 percent. Furthermore, a twisted single vegetable fiber will shorten only slightly, whereas it is easy to understand that a twisted single animal fiber will perhaps become lengthened, while a silk cord is shortened.

13. Chemical Composition and Properties.—Although cellulose forms the chief constituent of all vegetable fibers, it varies much in its purity and associated products in its occurrence in the various fibers. Seed-hairs, like cotton, consist almost entirely of cellulose in a rather pure state, but the bast and vascular fibers always contain more or less alteration products of cellulose, chief among which is ligno-cellulose, or lignin; in fact jute is almost entirely composed of this latter substance. Seed-hairs mostly consist of one single cell to the individual fiber and have very little foreign or incrusting material present. The other fibers are made up of an aggregation of cells bound together in a compact form, and in the cell interstices, there is always present more or less gummy and resinous matter, oils, mineral matter, and lignified tissue.

All vegetable fibers appear to contain more or less pigment matter, usually of a slight yellowish or brownish color. In ordinary cotton and ramie this coloring matter occurs in only a very small amount and the natural fiber is quite white in appearance. There are some varieties of cotton, however, which are distinctly brown in color. Flax, jute, hemp, etc., contain a considerable amount of pigment and are of a more or less pronounced brownish color.

In their chemical composition vegetable fibers consist of three parts, cell tissue (cellulose), woody tissue (lignin), and cork tissue (cutose). The first is the basic ingredient of all plant membranes. The following are the distinguishing reactions of these three tissues:

1. *Pure cell tissue* is recognised by giving blue colorations with chlor-iodide of zinc and iodine-sulfuric acid reagent. It is soluble in ammoniacal copper oxide and in concentrated sulfuric acid without a brown coloration.

2. *Woody tissue* gives a yellow coloration with chlor-iodide of zinc and also with aniline sulfate, while with phloroglucinol reagent it gives a red coloration. It is soluble in concentrated sulfuric acid with a strong brown coloration, but is insoluble in ammoniacal copper oxide solution.

3. *Cork tissue* also gives a yellow coloration with chlor-iodide of zinc, but beyond this shows no especially characteristic reaction. It is insoluble in both ammoniacal copper oxide and concentrated sulfuric acid. It is somewhat soluble, however, in boiling caustic potash solution.

Both the woody tissue and the cork tissue may be removed from the cell membrane proper by treatment with suitable chemical reagents, without destroying the form of the fibrous elements. Boiling with Schulze's reagent (nitric acid and potassium chlorate) will cause the decomposition of vegetable membranes into their fiber elements while still preserving the original form of the fiber. The same decomposition occurs in the technical preparation of wood-pulp, where the wood is boiled with dilute alkali or sulfurous acid under high pressure.

Besides cellulose and lignin, there is also present, especially in seed-hairs, a cutose membrane (cork tissue) in the form of an external cuticle. Cutose is insoluble in concentrated sulfuric acid, but is slightly soluble in boiling caustic potash. It doubtless originates from the plant-wax which is imbedded in the cell.

Albuminous matter also occurs in the fiber elements, mostly as a dried tissue which fills the lumen of the fiber more or less completely. It also occurs as a thin film which coats the inner wall of the cell and remains undissolved when the fiber is treated with concentrated sulfuric acid. This membrane exhibits all the reactions of albumen. Silicic acid sometimes is present in vegetable fibers, but only in the walls of the stegmata and in epidermal cells. On ignition the silicious matter is left in almost its original form. The silicious skeleton is insoluble in hydrochloric acid, whereas the rest of the ash is readily dissolved by this reagent. Many fibers derived from monocotyledonous plants exhibit under the microscope characteristic fragments of mineral matter known as *stegmata*. These are generally crystalline in structure and consist of calcium oxalate, although amorphous particles of silicious matter are also to be noticed at times. These silicious particles often occur in the form of a string of beads, a form which persists even after the fiber has been reduced to an ash by ignition. The silicious skeletons may also be observed when the cellulose of the fiber has been destroyed by treatment with chromic acid. Stegmata are especially to be observed in coir (cocoanut fiber), Manila hemp, and piassava fiber. Crystals of calcium oxalate occasionally occur in some fibers; they are insoluble in acetic but dissolve in hydrochloric acid. On ignition of the fibers these crystals are converted into calcium carbonate without much change of form, and then are soluble in even very dilute acids.

Woody fiber is to be found in many vegetable fibers, and its presence always lowers the economic value of the fiber. The presence of woody fiber may readily be determined by the application of a number of characteristic chemical tests. Aniline sulfate, for instance, with woody fiber gives a golden yellow color; phloroglucinol with hydrochloric acid gives a red color, phenol with hydrochloric acid a green color, as does also indol with hydrochloric acid, and a solution of chlor-iodide of zinc gives a

brownish yellow color. Woody fiber is also destroyed by the action of alkalies and hypochlorites in the bleaching process; and in fact this process usually has for its chief object the decomposition and removal of the woody fiber which may be present. Due to this fact, certain bleached fibers, such as jute and hemp, may no longer exhibit the above-mentioned color reactions, although they may have done so originally in the raw condition.

There are several reagents which are serviceable in micro-chemical tests on vegetable fibers, as they yield distinctive color reactions. With the iodine-sulfuric acid reagent the principal fibers give the following reactions:

(*a*) Blue Colors:
Cotton.
Raw fiber from *Hibiscus cannabinus.*
" " " *Calotropis gigantea* (greenish blue to blue).
" flax fiber.
Cottonised ramie.
Raw sunn hemp (often copper-red).
" hemp (greenish blue to pure blue).

(*b*) Yellow to Brown Colors:
Bombax cotton.
Vegetable silk (occasionally greenish or greenish blue).
Raw jute.
" fiber of *Abelmoschus tetraphyllos.*
" " *Urena sinuata.*
" " *Bauhinia racemosa* (blackish brown).
" " *Thespesia lampas.*
" esparto (reddish brown).
" aloe (mostly reddish brown, sometimes greenish and even blue).
New Zealand flax (yellow, green to blue, depending on the purification of the fiber).

14. Lignin.—The fibers in the second class have their cellulose largely contaminated with lignin, and hence have somewhat of the character of woody tissue. It is to be remarked, however, that by treatment with nitric acid (or by boiling with caustic potash under pressure) these fibers lose most of the lignin which encrusts their tissues, and then exhibit the characteristics of ordinary cellulose; that is to say, they dissolve in Schweitzer's reagent, and are colored blue with the iodine-sulfuric acid reagent.

Ammoniacal copper oxide (Schweitzer's reagent) is a reagent which gives characteristic reactions with many vegetable fibers, as follows:

(*a*) The Fibers are almost Completely Dissolved: [1]
Cotton.
Cottonised ramie.

[1] With the exception of the external cuticle, the inner cell-wall, and dry protoplasmic residue. For the morphological alterations which the fibers undergo by treatment with this reagent, see under the description of the separate fibers.

Raw fiber of *Hibiscus cannabinus.*
" " *Calotropis gigantea.*
" flax.
" hemp (only the bast cells dissolve, the accompanying parenchymous cells remain undissolved).
" sunn hemp.

(*b*) The Fiber becomes Blue in Color and is More or Less Swollen:
Raw jute.
" fiber of *Abelmoschus tetraphyllos.*
" " *Urena sinuata.*
" " *Bauhinia racemosa.*
" " *Thespesia lampas.*
" New Zealand flax.
" fiber of *Aloë perfoliata* (slightly swollen).
" " *Bromelia karatas* (strongly swollen).
" " *Sida retusa* (becomes greenish at first, then blue and swells up).

(*c*) The Fiber is Colored Without Swelling:
Vegetable silk (blue).
Bombax cotton (blue).
Raw esparto (bright green).
" fiber of *Cordia latifolia* (blue).
" " *Sterculia villosa* (blue).

A solution of aniline sulfate may be used to detect lignification in a fiber; this reagent gives the following color reactions:

(*a*) The Color of the Fiber is not Changed or but Slightly:
Cotton.
Bombax cotton (very slight coloration).
Cottonised ramie, also the bast cells of raw ramie.
Raw flax.
" bast fibers of *Hibiscus cannabinus* (very slight coloration).
" " " *Calotropis gigantea* (very slight coloration).
" sunn hemp.
" New Zealand flax (very slight coloration).
Manila hemp (very slight coloration).

(*b*) The Fiber is Distinctly or Very Strongly Colored:
Vegetable silk (intense citron-yellow).
Raw jute (golden yellow to orange).
" bast fibers of *Abelmoschus tetraphyllos* (golden yellow).
" " " *Urena sinuata* (golden yellow).
" " " *Sida retusa* (yellow).
" " fiber of *Thespesia lampas* (golden yellow).
" " " *Cordia latifolia* (dull yellow).
" hemp (pale yellow).
" esparto (sulfur yellow).
" fiber of *Bromelia karatas* (golden yellow).

A method for the estimation of the amount of lignin in fibers is given by Herzog.[1] It is based on a determination of the *methyl value,* that for pure lignin being taken as 52.9.

[1] *Chem. Zeit.,* vol. 20, p. 461.

The following table gives the methyl value and corresponding amount of lignin in the different fibers:

Fiber.	Water, Percent.	Methyl Value on Fiber Dried at 100° C.	Lignin, Percent.
Bombax cotton	6.77	6.87	12.99
Vegetable silk (*Calotropis gigantea*)	6.88	8.18	15.46
Manila hemp	6.81	15.92	30.11
Pita	7.10	8.47	16.02
Aloe	7.90	9.11	17.32
Coir	7.36	22.00	41.59
Tillandsia	8.10	11.18	21.13
Nettle	8.15		
Ramie	7.84	0.77	1.46
Fiber of *Morus papyrifera*	6.08	2.50	4.74
Linen, Russian	8.40	4.81	0.92
" Courtrai	8.71		
Hemp, Italian	7.93	2.80	5.33
" Polish	8.20	2.87	5.46
Jute	8.06	21.20	40.26

When a substance containing a methoxyl group is heated with hydriodic acid, methyl iodide is formed, and the so-called "methyl value" refers to the amount of methyl iodide thus formed. The determination is carried out as follows: The fibrous material is finely divided and from 0.2 to 0.3 gram is heated with 10 cc. of hydriodic acid (sp. gr. 1.70) in a flask on a glycerol bath, while a current of carbon dioxide gas is passed through the flask. The vapors produced are passed through a three-bulb condenser, the first bulb being empty to condense the steam, the second containing water to absorb the hydriodic acid, and the third containing red phosphorus to retain any iodine liberated by the decomposition of the hydriodic acid. The vapors of methyl iodide (mixed with carbon dioxide) issuing from the bulbs are passed into a flask containing a mixture of 5 cc. of a 40 percent solution of silver nitrate with 50 cc. of 95 percent alcohol. The methyl iodide is precipitated as silver iodide, which is weighed in the usual manner; 100 parts of silver iodide are equivalent to 6.4 parts of methyl.

15. Chemical Investigation of Vegetable Fibers.—A chemical study of the fibers involves an examination of their chemical constituents. As previously stated, though cellulose is the principal chemical compound to be found in vegetable fibers, yet there are certain other substances present, which at times may be characteristic of the fiber. Then, again,

the cellulose which occurs in different classes of fibers appears to be somewhat different in its chemical properties, which has led to the supposition of different forms of cellulose, already spoken of as ligno-cellulose, pecto-cellulose, etc. Though the chemistry of these bodies has been somewhat studied with reference to vegetable fibers by Cross and Bevan and a few others, yet the subject is still in a very crude condition, and there is much to be learned in this field of chemical research. The methods for the chemical study of the vegetable fibers adopted by Cross, and continued by other chemists, may be stated in the following form:

A separate portion of the fiber under examination is taken for each determination, and the results are calculated into percentages on the dry weight of the substance.

(1) *Moisture.*—This may be called hygroscopic water or water of condition; it is obtained by drying a weighed portion of the fiber at 110° C. to constant weight.[1] If dried at 100° C., about 1 percent of the water will be retained. The percentage of hygroscopic moisture in the vegetable fibers varies considerably with the different state of humidity of the surrounding air, on which account it is recommended that the results of the analyses should be expressed on the dry weight of the fiber. It is interesting to note that the contents of hygroscopic moisture in a fiber appears to be an index of susceptibility of attack by hydrolytic agents, and that the highest class of fibers is distinguished by its relatively low amount of moisture.

(2) *Ash.*—This is taken as the total residue left after ignition of the fiber, and represents the mineral constituents. The proportion of these is low in the ligno-celluloses and higher in the pecto-celluloses, especially when the proportion of non-cellulose is high. Admixture of non-fibrous tissue will also raise the amount of ash, as this tissue contains a higher proportion of mineral constituents. The natural ash of vegetable fibers varies from 0.5 to 2 percent, and usually the major portion of this consists of silica. The exact function of this silicious matter in the plant cell is not known; according to Ladenburg (*Berichte*, 1872, p. 568) and Lange (*Berichte*, 1884, p. 822) the silica does not have any structural function in the cell.

(3) *Hydrolysis.*—This refers to the loss of weight sustained by the fiber (*a*) on boiling for five minutes with a 1 percent solution of caustic soda, and (*b*) further loss of weight on continuing to boil for one hour. The first loss in weight represents the proportion of fiber soluble in the alkali, the second represents the proportion of the fiber decomposed by actual hydrolysis. The pecto-celluloses are often so resolved by the action of the dilute alkali that most of the non-cellulose is dissolved away. The amount of hydrolysis of a fiber represents in some measure the power of resistance of a fiber to the action of the boiling-out and bleaching processes, as well as the power of resistance to actual wear as caused by frequent washings with alkalies, soaps, etc.

(4) *Cellulose.*—The determination of the value and composition of the cellulose is made as follows: A sample of the fiber is first boiled for five minutes in a 1 percent solution of caustic soda, well washed, and then exposed for one hour at the ordinary temperature to an atmosphere of chlorine gas; after which it is removed, washed, and treated with an alkaline solution of sodium sulfite, gradually raising to the boil. After several minutes the fiber is washed, and finally treated with dilute acetic acid,

[1] According to Ostwald, water is held in combination with cellulose fibers in five different forms: (1) as water of the cellulose, (2) as capillary water, (3) as colloidal water, (4) as osmotically combined water, (5) as chemically combined water, or water of hydration.

washed, dried, and weighed. The residue is taken as cellulose, and affords an important criterion as to the composition and value of the raw fiber.

(5) *Mercerising.*—This is represented by the loss in weight sustained by the fiber after treatment for one hour cold with a 33 percent solution of caustic potash. The action of the alkali often causes a considerable change in the structure of the fiber, especially with those fibers made up of a number of fibrils aggregated into bundles.

(6) *Nitration.*—This is represented by the increase in weight sustained by the fiber when treated for one hour with a mixture of equal volumes of nitric and sulfuric acids. Any change in color is also noted.

(7) *Acid Purification.*—This is represented by the loss in weight sustained by the fiber after boiling with 20 percent acetic acid, washing with alcohol and water, and drying. This treatment is intended to remove from the fiber all accidental impurities with a minimum alteration in composition.

(8) *Carbon Percentage.*—The fiber treated as above (7) is subjected to a combustion in the presence of chromic anhydride and sulfuric acid, and the resulting gas, composed of a mixture of carbon monoxide and dioxide, is collected and measured. As the two oxides of carbon have the same molecular volume, the amount of carbon in unit volume is independent of the composition of the gas. The amount of carbon in cotton cellulose (the typical cellulose) is 44.4 percent; the compound celluloses, however, have either a lower percentage in the one class (40 to 43 percent), or a higher percentage in the second class (45 to 50 percent), the pecto-celluloses being included in the first class and the ligo-celluloses in the second class.

The following table shows the results obtained with the principal fibers when analysed by the above method:

		Moisture, Percent.	Ash, Percent.	Hydrolysis.		Cellulose, Percent.	Mercerising, Percent.	Nitration, Percent.	Acid Purification, Percent.	Carbon, Percent.
				a, Percent.	*b*, Percent.					
A	Flax	9.3	1.6	14.6	22.2	81.9	8.4	123.0	4.5	43.0
	Ramie	9.0	2.9	13.0	24.0	80.3	11.0	125.0	6.5	
	Calotropis	7.3	2.5	13.0	17.6	76.5	.....	153.0	8.5	44.6
	Marsdenia	4.5	1.5	6.2	10.1	88.3	4.6	131.0	0.8	44.3
	S. hemp	8.5	1.4	8.3	11.7	83.0	11.3	150.5	2.7	47.0
B	Jute	10.3	1.1	13.3	18.6	76.0	11.0	128.0	2.5	45.2
	Sida retusa	10.7	0.6	6.6	12.2	83.1	6.6	137.2	0.4	
	Urena	10.7	1.8	11.9	18.5	77.7	13.6	.....	4.0	
	Hibiscus can.	10.6	2.2	14.0	19.5	73.0	16.0			
	Hibiscus sp.	10.7	1.5	9.8	14.2	74.0	9.6	.....	3.4	45.2
C	*Agave amer.*	10.5	1.4	10.0	20.0	75.8	11.0	109.8	1.1	44.9
	Sansevieria sp.	9.7	....	12.0	16.5	73.1	.....	106.0	2.5	44.5
	Musa	13.4	....	11.0	33.0	64.6	11.0	91.3	4.0	
	Fourcroya	12.2	....	...	11.8	70.0	.....	104.0		

CHAPTER XIII

COTTON

1. Historical.—The use of cotton as a textile fiber dates back to antiquity, mention of it being found in the writings of Herodotus (445 B.C.): "There are trees which grow wild there (India), the fruit of which is a wool exceeding in beauty and goodness that of sheep. The Indians make their clothes of this tree-wool." The same writer also refers to the clothing of Xerxes' army as being composed of "cotton fiber." Theophrastus (350 B.C.) gives a definite statement as to manner in which the cotton plant was cultivated in India. Cotton was used in India, Egypt, and China. The first European country to manufacture cotton goods appears to have been Spain.

A rather ambiguous passage in the *Historia Critica de España* indicates that the manufacture of linen, silk, and cotton existed in Spain as early as the ninth century. De Marles states that cotton manufacture was introduced into Spain during the reign of Abderahman III., in the tenth century, by the Moors. In the fourteenth century Granada was noted for its manufacture of cotton. A commercial historiographer of Barcelona states that one of the most famous and useful industries of that city was the manufacture of cotton; its workers were united in a guild in the thirteenth century, and the names of two of its streets have preserved the memory of the ancient locality of their shops. There is much uncertainty as to when the manufacture of cotton was first introduced into England; the first authentic record of such is in Robert's *Treasure of Traffic*, published in 1641.

The use of cotton in India dates back to prehistoric times, and it is often referred to as early as 800 B.C. in the ancient laws of Manu. It may be stated that from 1500 B.C. to about the beginning of the sixteenth century, India was the center of the cotton industry, and the cloth which was woven in a rather crude and primitive manner has rarely been equaled for fineness and quality.

The earliest mention of cotton appears to be in the *Asvaláyana Sranta Seitra* (about 800 B.C.). The following quotations are from the *Books of Manu.* The sacrificial thread of the Brahmin must be made of cotton (*karpasi*), so as to be put over the head in three strings. Let a weaver who has received 10 palas of cotton thread give it back increased to 11

by the rice-water and the like used in weaving; he who does otherwise shall pay a fine of 12 panas. Theft of cotton thread was made punishable by fines of three times the value of the article stolen. In the Hebrew *Scriptures* cotton is mentioned under the name *Kirbas* (or *Karpas*), as when describing the green draperies at the palace of Susa (*Esther* I, 6.) Among the Latin authors of the Augustan age curtains and tents of *carbasa* are frequently mentioned.

Two Arabian travelers of the Middle Ages, writing of India, say: "In this country they make garments of such extraordinary perfection that nowhere else are the like to be seen; these garments are woven to that degree of fineness that they may be drawn through a ring of moderate size." Marco Polo, about A.D. 1298, mentions India as producing "the

FIG. 154.—Microphotograph of Ordinary American Cotton.

finest and most beautiful cottons that are to be found in any part of the world." Tavernier, in his *Travels*, says of India that some calicoes are made so fine that one can hardly feel them in the hand, and the thread when spun is scarcely discernible; that the rich have turbans of so fine a cloth that 30 ells of it weigh less than 4 ozs. The poetic writers of the Orient call these cloths "webs of woven wind." There is the record of a muslin turban thirty yards in length, contained in a cocoanut set with jewels, which was so exquisitely fine that it could scarcely be felt by the touch.[1]

[1] The superior fineness of some Indian muslins, and their quality of retaining, longer than European fabrics, an appearance of excellence, has occasioned the belief that the cotton fiber from which they are woven is superior to any known elsewhere; this, however, is so far from being the fact, that no cotton is to be found in India that at all equals in quality the better kinds grown in the United States. The excellence of these Indian muslins must be wholly ascribed to the skillfulness and patience of

Cotton was introduced into China and Japan from India, but its adoption by these countries was slow. Fesca (*Japanische Landwirthschaft*, Pt. II, p. 485) says that cotton was introduced into Japan accidentally in the year A.D. 781 from India, but its cultivation was not continued. Several centuries later it was no doubt introduced again by the Portuguese; it was not, however, until the seventeenth century, during the reign of Tokugawa, that the cultivation of cotton became at all general in Japan. A great deal of cotton is now grown in Korea, having been introduced into that country from China about 500 years ago. The Korean cotton is of longer staple and of better quality than the Chinese cotton, as the soil and climate in Korea are better adapted to its growth. In the seventh century the cotton plant was used as an ornamental shrub in Chinese gardens; and it was not until about A.D. 1000 that the plant was commercially grown in China.

Cotton was probably introduced into China at the time of the conquest of this country by the Tartars, but it was not until about A.D. 1300 that the fiber was cultivated for manufacturing purposes. Marco Polo (*Book II*, Ch. 24) gives no account of the culture of cotton in China, except in the province of Fo-Kien, but speaks of silk as being the customary dress of the people.

In Egypt there is some question as to whether or not cotton was used except in rather late times, flax being the common article in that country for the manufacture of cloth. But there is evidently a good deal of confusion in the early writers respecting the terms used for "flax" and "cotton," and it may be that the ancient Egyptians were better acquainted with the use of the cotton fiber than we imagine; we at least know that the cotton plant was grown there at a very early date. Herodotus states that the Egyptian priests wore linen clothes, but Pliny refers to them as also wearing cotton material, and Philostratus supports this latter statement. The words translated as "linen" do not always refer to the fiber of which the cloth was made, but often have reference to the general appearance of the material; therefore, cloth made from either flax or cotton alone, or mixed, was called linen. Even the fact that all Egyptian mummy-cloths so far examined appear to consist of flax is no argument against the probable use of cotton by these people; it only proves that flax alone

the workmen, as shown in the different processes of spinning and weaving. Their yarn was spun upon a distaff and it is owing to the dexterous use of the finger and thumb in forming the thread, and to the moisture which it imbibes, that these fibers are more perfectly incorporated than they can be through the employment of any mechanical substitutes. The very fine muslins which thus attest the efficiency of some of the East Indians, and which have been poetically described as "webs of woven wind," are, however, viewed as curiosities even in the country of their production, and are made only in very small quantities.

was employed for certain religious purposes, and cotton, wool, and silk, may have been in common use for the clothing of the people.

The use of cotton was evidently known to the Greeks soon after the invasion of India by Alexander, though this does not signify that the Greeks themselves either grew the cotton plant or engaged in the manufacture of the fiber into clothes. Aristobulus, a contemporary of Alexander, mentions the cotton plant under the name of the "wool-bearing tree," and states that the capsules of this tree contain seeds which are

Fig. 155.—American Upland Cotton Shrub. (After Dodge.)

taken out, and the remaining fiber is then combed like wool. Nearchus, an admiral of Alexander, about 327 B.C., says: "There are in India trees bearing, as it were, bunches of wool. The natives made linen garments of it, wearing a shirt which reached to the middle of the leg, a sheet folded about the shoulders, and a turban rolled around the head. The linen made by them from this substance was finer and whiter than any other."

The cotton plant does not appear to have been cultivated in Italy until some time after the beginning of the Christian era, although a knowledge of the fiber and a probable use of the cloth made from it was

no doubt known to them a long time previous. Müller[1] states that cotton cloth was used for clothing by the Romans prior to A.D. 284 For the real introduction into Europe of the cotton plant and the manufacture of the fiber into cloth we must look to the Mohammedans, who spread this knowledge throughout the countries bordering on the Medi-

Fig. 156.—Sea-island Cotton Shrub. (After Dodge.)

terranean Sea during the period of their wide-spread conquests. Abu Zacaria Ebn el Awam, a Moorish writer of the twelfth century, gives a full account of the proper method of cultivating the cotton plant, and also mentions that cotton was cultivated in Sicily.

The various names given to the cotton fiber in different countries may be of interest; they are as follows:

[1] *Handbuch der klas. Alterth. Wissensch.*, vol. 4, p. 873.

India	Pucü
Spain	Algodon
Yucatan and ancient Mexico	Ychcaxihitvitl
Tahiti	Vavai
France	Coton
Italy	Cotone
Germany	Baumwolle
Persia	Pembeh or Poombeh
Arabia	Gatn, Kotan, or Kutn
Cochin China	Cay Haung
China	Hoa mein
Japan	Watta ik or Watta noki
Siam	Tonfaa
Hindoostan	Nurma
Mysore and Bombay	Deo Kurpas and Deo Kapas
Mongolia	Kohung

The English word " cotton " is, in fact, derived from the Arabic *Katán* (or *qutn, kuteen*), though it is claimed this name originally denoted flax. The word *linon* was itself at one time used to denote cotton, and even at the present time we speak of the cotton fibers as *lint*. In early times it was used rather to denote a particular texture than to describe a distinct fiber. For instance, we find "Manchester Cottons" (1590) as a name for a certain woolen fabric. England first came into prominence as a cotton manufacturing country in 1635, the supply of the raw fiber being obtained from the East. Long previous to this, however, England as well as other European countries, had imported cotton goods (calicoes, etc.) from India by way of Venice. The introduction of the cheaper cotton fabrics was vigorously opposed in England as being destructive

Fig. 157.—Leaf of the Cotton Plant.

of the woolen industry. By an Act of 1720 the use and wear in England of printed, painted, or dyed calicoes was prohibited. As to the knowledge and use of cotton in the Western Hemisphere, this also seems to have extended to very early times, for when Columbus first came to the West Indies in 1492, he found cotton extensively cultivated, and the inhabitants of these islands wove cloth from the fiber. Among the Mexicans cotton was found to be the chief article of clothing, as these people did not possess either wool or silk and were not acquainted with the use of flax, although the plant grew in their country. Among the presents sent by Cortez to Charles V. of Spain were many fabrics made from cotton. In Peru cotton was also in use from an early date, and at the time of Pizarro's conquest of that country in 1522 the inhabitants were clothed in cotton garments; cotton cloths have also been found on Peruvian mummies of a very ancient date. Furthermore, the cotton plant is indigenous to Peru and from it is obtained a special variety known as Peruvian cotton. According to Bancroft, the first attempt towards cotton cultivation in the American colonies was in Virginia, during Wyatt's administration, in 1621. In 1733 the cultivation of cotton was started in Carolina, and the following year in Georgia. In 1748 the first consignment of Georgian cotton was sent to England. In 1758 white Siam cotton was introduced into Louisiana. In 1784 fourteen bales of cotton arrived in Liverpool from America, of which eight bales were seized on the ground that so much cotton could not have been produced in the United States. In 1786 the black-seeded cotton from the Bahamas was introduced into Georgia.

Fig. 158.—Leaf and Flower of Sea-island Cotton. (After *Bulletin No.* 33, U. S. Dept. Agric.)

The first mill in the United States for the manufacture of cotton goods appears to have been erected at Beverly, Massachusetts, in 1787.

2. Origin and Growth.—The cotton fiber consists of the seed-hairs of several species of the genus *Gossypium*, belonging to the natural order of *Malvaceæ*.[1] The cotton plant is a shrub which reaches the height of four to six feet. It is probably indigenous to nearly all subtropical countries, though it appears to be best capable of cultivation in warm, humid climates where the soil is sandy, and in the neighborhood of the

[1] The following is a description of the botany of cotton given in *Bulletin* No. 33 of the U. S. Department of Agriculture: The cotton plant belongs to the *Malvaceæ*, or the mallow family, and is known scientifically by the generic name *Gossypium*. It is indigenous principally to the islands and maritime regions of the tropics, but under cultivation its range has been extended to 40° or more on either side of the equator, or to the isothermal line of 60° F. In the United States latitude 37° north about represents the limit of economic growth. The *Gossypium* plant is herbaceous, shrubby, or arborescent, perennial, but in cultivation herbaceous and annual or biennial, often hairy, with long, simple, or slightly branched hairs, or soft and tomentose, or hirsute, or all the pubescence short and stellate, rarely smooth throughout; stem, branches, petioles, peduncles, leaves, involucre, corolla, ovary, style, capsule, and sometimes the cotyledons more or less covered with small black spots or glands. Roots tap-rooted, branching, long, and penetrating the soil deeply. Stems erect, terete, with dark-colored ash-red, or red bark and white wood, branching or spreading widely. Branches terete or somewhat angled, erect or spreading, or in cultivation sometimes very short. Leaves alternate, petioled, cordate, or subcordate, 3- to 7-, or rarely 9-lobed, occasionally some of the lower and upper ones entire, 3- to 7-veined. Veins branching and netted; the midvein and sometimes adjacent ones bear a gland one-third or less the distance from their bases, or glands may be wholly absent. Stipules in pairs, linear-lanceolate, acuminate, often ceduous. Flowers pedunculate. Peduncles subangular or angular, often thickened towards the ends, short or very short, erect or spreading; the fruit is sometimes pendulous, sometimes glandular, bearing a leafy involucre. Involucre 3-leaved, or in cultivation sometimes 4; bracteoles often large, cordate, erect, appressed or spreading at summit, sometimes coalescent at base or adnate to the calyx, dentate or laciniate, sometimes entire or nearly so, rarely linear. Calyx short, cup-shaped, truncate, shortly 5 dentate or more or less 5-parted. Corolla hypogynous. Petals 5, often coalescent at base and by their claws adnate to the lower part of stamen tube, obovate, more or less unequally transversely dilated at summit, convolute in bud. Staminal column dilated at base, arched, surrounding the ovary, naked below, above narrowed and bearing the anthers. Filaments numerous, filiform, simple or branched, conspicuous, exserted. Anthers kidney-shaped, 1-celled, dehiscent by a semicircular opening into two halves. Ovary sessile, simple, 3- to 5-celled. Ovules few or many, in two series. Style clavate, 3- to 5-parted; divisions sometimes erect, sometimes twisted and adhering together, channeled, bearing the stigmas. Capsule more or less thickened, leathery, oval, ovate-acuminate, subglobose, mucronate, loculicidally dehiscent by 3 to 5 valves. Seed numerous, subglobose, ovate or subovate, oblong or angular, densely covered with cotton or rarely glabrous. Fiber sometimes of two kinds, one short and closely adherent to the seed, the other longer, more or less silky, of single simple flattened cells more or less spirally twisted, more readily separable from the seed. Albumin thin, membranous, or none. Cotyledons plicate, auriculate at base enveloping the straight radicle.

The *Malvaceæ* is represented by about one thousand different species, a great many of which are of some economic value to man.

sea, lakes, or large rivers. It appears to thrive most readily in North and South America, India, and Egypt; it has also been cultivated in Australia, but not as yet with any great degree of success; inferior qualities have been grown along the coasts of Africa; that grown in Europe (Italy and Spain) is practically negligible as far as commercial considerations are concerned. In addition to the numerous varieties of cultivated cottons, there are various wild cotton plants to be met with in many parts of the world. With respect to the detailed botany of these wild plants, the reader is referred to the very able treatise by Sir George Watt on *The Wild and Cultivated Cotton Plants of the World*. As to the general characteristics of these wild cottons, it may be said that they all have a red-colored woolly coating on the testa of the seed. In some this assumes the condition of a short dense velvet, called the *fuzz*. In others, there are two coats of fiber, an under-fleece (the fuzz) and an outer coat or floss. In the third class there is no fuzz, but a distinct floss.

Fig. 159.—Leaf and Flower of India Cotton, *Gossypium herbaceum*. (After *Bulletin No.* 33, U. S. Dept. Agric.)

Monie gives the following account of the cultivation of the cotton plant: "The plant, although indigenous to almost all warm climates, is nevertheless only cultivated within a very limited area for commercial purposes, the principal centers of cotton agriculture being in Egypt, the southern portions of the United States, India, Brazil, the west and southern coasts of Africa, and the West India Islands. A large amount of white cotton is raised in China, but this is almost entirely used in the home manufactures. The time when sowing is begun in the different districts varies considerably, being largely dependent on climatic influences. The seasons, however, are generally as follows: American.—From the middle of March to the middle of April. Egyptian.—From the beginning of March to the end of April. Peruvian and Brazilian.—From the end of

December to the end of April. Indian or Surat.—From May to the beginning of August. In the various American plantations the sowing time begins and ends almost simultaneously, while in other countries, especially where the atmosphere and climate are subject to much variation, the period of planting fluctuates; the plants in some parts being several inches above the ground, while in other parts of the same country the fields may be only under preparation. When the sowing is finished, and before, and some time after the crop makes its appearance, keeping the ground free from weeds is the main object to be looked to, otherwise the soil would become much impoverished and the product would be of an inferior quality. In from eight days to a fortnight after sowing, the young shoots first appear above ground in the form of a hook, but in a few hours afterwards the seed end of the stalk or stem is raised out of the

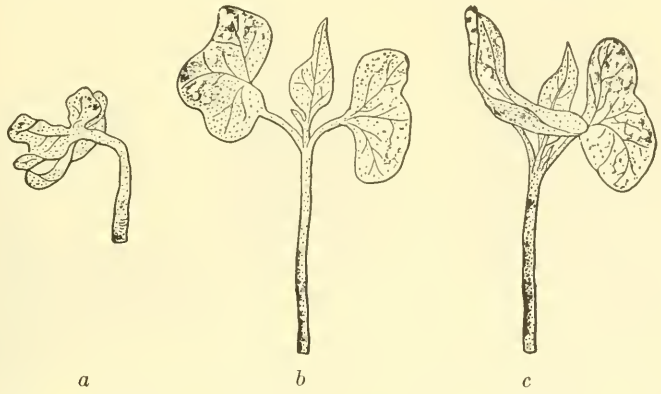


Fig. 160.—The Cotton Plant in the Early Stages of Its Growth.

ground, disclosing two leaves folded over and closed together. The leaves and stems of these young plants are very smooth and oily and of a fleshy color and appearance, and, as before stated, extremely tender (Fig. 160, *a*). In a short time after the plant has reached the stage shown in the illustration, it begins to straighten itself and deepen in color, or, rather, changes to a light olive green, while the two leaves gradually separate themselves until they attain the forms shown in Fig. 160, *b* and *c*. When this stage has been reached its development is rapid, and proceeds in a similar form to ordinary shrubs until it reaches maturity.

"In examining the cotton plant from time to time during its growth some interesting and instructive objects will be observed. Firstly, in regard to the formation of the leaves, it will be found that they vary in shape on different parts of the stem. Thus, for instance, on a Gallini Egyptian (*G. barbadense*) plant the lower leaves were entire, the center or middle three-lobed, while the upper leaves were five-lobed. In the

G. hirsutum species the lower leaves have five, and some three lobes, with the small branch petioles of a hairy nature, while the upper leaves are entire and undivided. In the Peruvian cotton plant the lower leaves are entire and of an oval shape, while the upper leaves have five acuminated lobes.

"Another interesting point observable in the growth of the cotton plant is the presence of a small cavity situated at the lower end of the main vein under each leaf. Through this opening, on warm days, the plant discharges any excess of the resinous matter which circulates through its branches. Before the plant attains its full height it begins to throw off flower-stalks, which are generally (when perfectly formed) small in diameter and of considerable length; on the extremity of these stalks the blossom

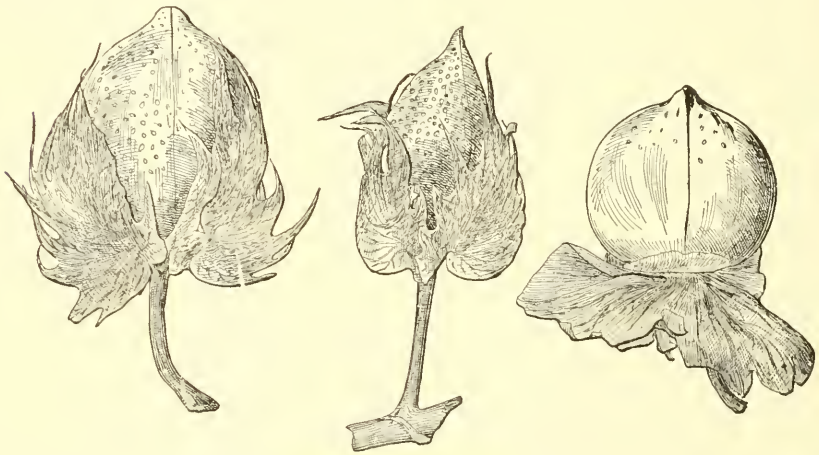


Fig. 161.—Cotton Bells.

pod after a time appears, encased in three leaf-sheaths or calyxes, with fringes of various lengths. Gradually this pod expands until it attains to about the size of a bean, when it bursts and displays the blossom. This blossom only exists in full development for about twenty-four hours, when it begins to revolve imperceptibly on its axis and in about a day's time twists itself completely off. When the blossom has fallen, a small three- and, in some cases, five-celled triangular capsular pod of a dark-green color is disclosed, which increases in size until it reaches that of a large filbert (Figs. 161 and 162). Meantime the seeds and filaments have been in course of formation inside the pod, and when growth is completed the expansion of the fiber causes it to burst into sections, in each cell of which, and adhering firmly to the surface of the seeds, is a tuft of the downy material."

In America, India, and Egypt the cotton plant is annual in its growth, but in hot tropical climates, and in South America, it becomes a perennial plant and assumes more of a treelike form.

According to von Humboldt, that portion of the world lying between the equator and the 34th degree of latitude presents the most suitable conditions for the cultivation of the *Gossypium barbadense, G. hirsutum,* and *G. arboreum* cottons, a mean yearly temperature of 68° to 86° F. being required. *G. herbaceum* is best cultivated in zones where the temperature in winter does not fall below 50° F., nor in summer rise above 77° F. In the United States the cotton plant is cultivated up to 37° north latitude, but the best fiber is obtained from along the eastern coast between 25° 10′, and 32° 40′ north latitude, which includes the states of Florida, Georgia, and South Carolina. Proximity to the sea appears to have a beneficial influence on the quality of the cotton fiber, due, no doubt, to the salt-laden air and soil. This same fact is to be observed in Indian and Egyptian cottons. In fact, the only exception to this rule appears to be Brazilian cotton, that from the inland districts being of superior quality to that produced along the coast. The reason for this, however, is that the coast districts of Brazil have an excessive rainfall during nearly nine months of the year. In China and Japan cotton is cultivated readily as far north as 41°, and in Europe (Black Sea provinces) its cultivation reaches to 46°.

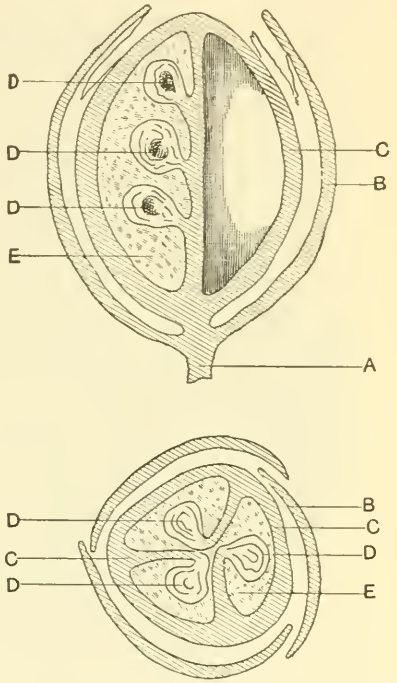


Fig. 162.—Sections of the Cotton Boll (Egyptian). (After Witt.) *A*, Stem; *B*, calyx; *C*, capsule; *D*, seed; *E*, cotton fiber.

The leaf of the cotton plant has three-pointed lobes; the flower has five petals, yellow at the base, but becoming almost white at the edges. The fruit of the cotton plant forms the cotton boll, which contains the seeds with the attached fibers. The cotton fiber is developed as a protective covering to the young seeds while still in their embryonic condition. This provision is not restricted to the cotton plant alone, but is common to many other species. The boll consists of from three to five segments,

and on ripening bursts open and discloses a mass of pearly white downy fibers, in which are imbedded the brownish black to black-colored cotton-seeds.

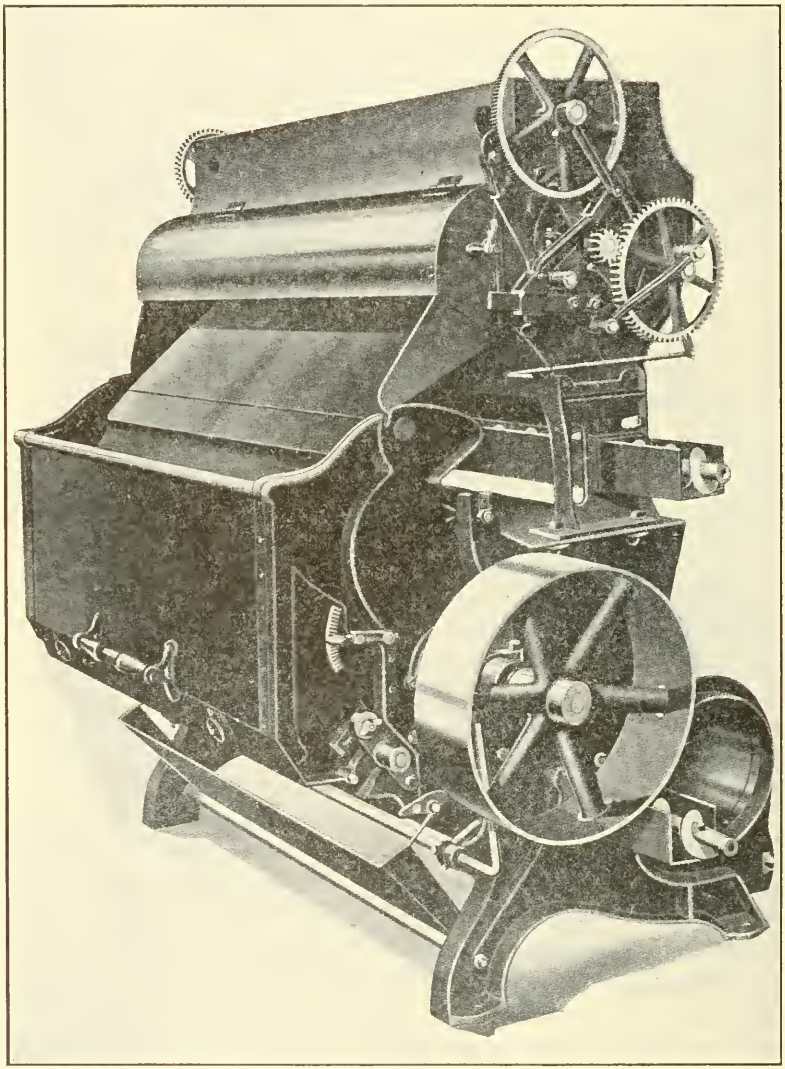


Fig. 163.—Pneumatic Huller Gin. (Murray Co.)

The time required for the maturity of cotton is divided as follows: From seeding to flowering, New Orleans 80 to 90 days, Sea-island 100 to 110 days; from flowering to maturity, New Orleans 70 to 80 days, and Sea-island about 80 days, making the total period of growth about 5 to

$6\frac{1}{2}$ months. The cotton should be picked as soon as possible after ripening; the seeds are then separated from the fibers by a process known as *ginning*.

3. Cotton Ginning.—Cotton which has been picked from the plant and still contains the seed is known as "seed cotton." Before the ginning process proper the seed cotton is often passed through cleaners for the purpose of breaking up any unopened bolls and disintegrating lumps of dirt, burrs, etc., which may be mingled with the cotton fibers. The principle on which the ginning depends is to pull the fiber through a

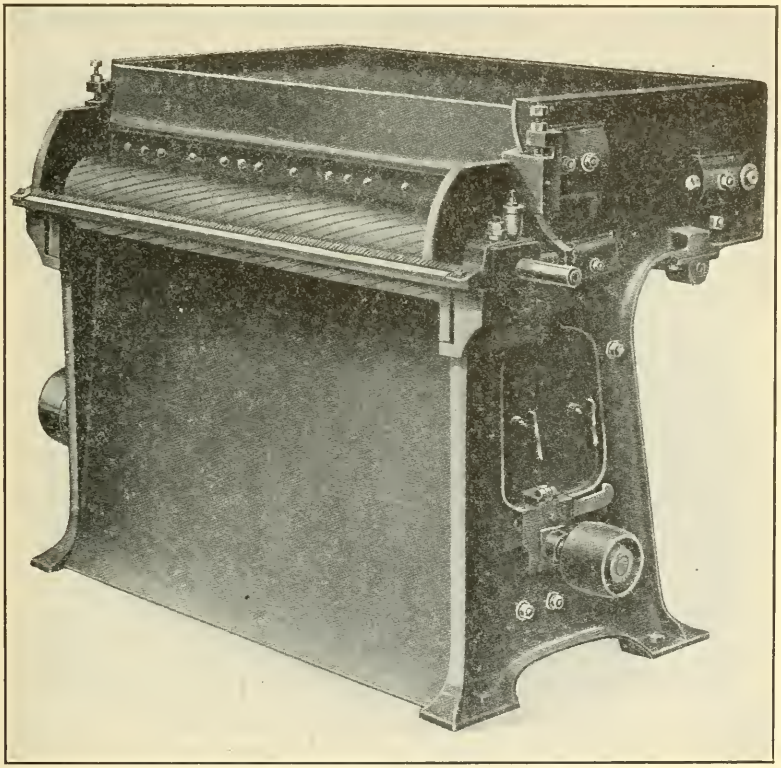


FIG. 164.—Long Staple Roller Gin. (Murray Co.)

narrow space which is too small to permit of the seed following. There are two types of cotton gins, the roller gin and the saw gin. The former is only used for long stapled cottons where the chief consideration is to preserve the length of the fiber. It has a much lower production in a given time than the saw gin. The latter was the invention of Eli Whitney, and is still the same in principle as when first invented in 1793. Briefly described, the saw gin consists of a box or hopper for holding the seed cotton; one side of this box is a grate composed of steel bars, through the intervals of which a number of thin steel discs, notched on the edge

(saws), rotate rapidly. The fibers are caught in the notches or teeth of these discs and thus pulled from the seeds, the latter as they are cleaned fall down through a slit below the grate. The fibers are carried off the revolving saws by means of a rapidly rotating cylindrical brush. The cotton fiber as ginned from the seed is technically known as "lint." In upland or ordinary American cotton, the seeds are not entirely freed from fiber by the ginning, there remaining more or less short fiber together with a fine undergrowth of fiber, amounting on an average to about 10 percent of the total weight of the seed. At the present time these seeds are further delinted by passing through specially constructed gins having

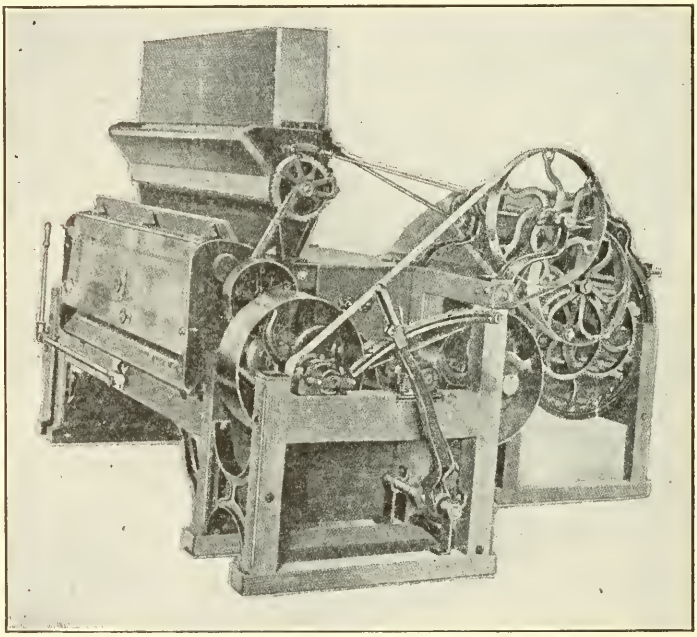


FIG. 165.—Linter Gin. (Carver Cotton Gin Co.)

saw-teeth closer set and finer. The fiber obtained in this manner is known as "linters," and is chiefly used for cotton-batting or is converted into guncotton.

4. Constituents of Cotton Plant.—Besides the fiber itself, nearly all of the other products of the cotton are now utilised commercially. The seeds are of especial value, as they contain a large quantity of oil, which is expressed and used for soapmaking and many other purposes, while the residuum of meal and hulls is converted into cattle foods and fertiliser.

The following table presents the fertilising constituents in a crop of cotton yielding 100 lbs. of lint per acre, expressed in pounds per acre. The weight of the total crop from the acre was 847 lbs.

Part of Plant.	Nitrogen.	Phosphoric Acid.	Potash.	Lime.	Magnesia.
Roots (83 lbs.)	0.76	0.43	1.06	0.53	0.34
Stems (219 lbs.)	3.20	1.29	3.09	2.12	0.92
Leaves (192 lbs.)	6.16	2.28	3.46	8.52	1.67
Bolls (135 lbs.)	3.43	1.30	2.44	0.69	0.54
Seed (218 lbs.)	6.82	2.77	2.55	0.55	1.20
Lint	0.34	0.10	0.46	0.19	0.08
Total (847 lbs.)	20.71	8.17	13.06	12.60	4.75

According to *Bulletin* No. 33 (U. S. Dept. Agric.) the following is the proportion of the different parts of the cotton plant, calculated on the dried or water-free material:

Part of the Plant.	Weight.		Percent.
	Ounces.	Grams.	
Roots	0.513	14.55	8.80
Stems	1.350	38.26	23.15
Leaves	1.181	33.48	20.25
Bolls	0.829	23.49	14.21
Seed	1.343	38.07	23.03
Lint (fiber)	0.615	17.45	10.56
Total	5.831	165.30	100.00

This table was compiled from the examination of a large number of plants and represents the average composition of the cotton plant as stated.

The following table presents the proximate percentage constituents of the various parts of the cotton plant as given by analyses of a large number of samples by the United States Department of Agriculture:

Part of Plant.	Water.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Entire plant	10.00	12.01	17.57	22.04	35.11	4.15
Roots	10.00	7.23	9.89	48.57	39.15	2.77
Stems	10.00	9.64	20.45	49.44	39.87	3.50
Leaves	10.00	12.87	21.64	12.57	36.82	6.05
Bolls	10.00	4.90	15.89	19.72	45.42	4.07
Seed	9.92	4.74	19.38	22.57	23.94	19.45
Lint	6.74	1.65	1.50	83.71	5.79	0.61

The following table shows the products obtainable from 2000 lbs. of cotton-seed:

A. Linters, 27 lbs.
B. Hulls, 841 lbs.
    1. Bran, Feeding stuffs.
    2. Fiber, High-grade paper.
    3. Fuel, Ashes and fertiliser.
C. Meats, 1012 lbs.
    1. Cake, 732 lbs.
        (*a*) Meal.
            (1) Feeding stuff.
            (2) Fertilizer.
    2. Crude oil, 280 lbs.
        (*a*) Soap stock, soaps.
        (*b*) Summer yellow.
            (1) Winter yellow.
            (2) Salad oil.
            (3) Cotton lard.
            (4) Cottolene.
            (5) Miner's oil.
            (6) Soap.

An Experiment Station Report shows that the seeds from upland cotton after ginning consist of 54.22 percent of kernels (yielding 36.88 percent of oil and 63.12 percent of meal) and 45.78 percent of hulls (yielding 27.95 percent of linters and 72.05 percent residue; so that in the ginned seed there is present the following:

	Percent.
Meal	34.22
Oil	20.00
Hulls	35.78
Linters	10.00

According to Adriane [1] the seeds from Egyptian cotton yield 37.45 percent of hulls and 62.55 percent of kernels.

5. Cotton Linters.—The short fibers, or nep, left on the seed after the first ginning are also recovered by a second process and are known as *linters;* they are used in the manufacture of cotton batting, guncotton, etc. With Sea-island and Egyptian cottons the seed is entirely freed from lint by ginning, but with upland cottons the quantity of lint still adhering to the seed after it has passed through the gin amounts to about 10 percent of the total weight of the seed.

According to Kress and Wells [2] cottonseed in the form in which it is delivered to the mills contains about 200 lbs. of adherent fiber per ton (2000 lbs.). The first cut yields about 75 lbs. of linters of a suitable

[1] *Chem. News*, Jan., 1865.
[2] *Pulp and Paper Mag.*, 1919, p. 697.

length for use as a stuffing material; a second cut, made with carborundum wheels or plates, yields 75 to 100 lbs. of linters, practically free from hull particles and easily purified for paper-making; after decortication, the residual hull fibers are treated in steel attrition mills and yield very specky shavings. The average length of the linters fiber is 4.62 mm., while the average length of the hull shavings fiber is 2.41 mm.

The separation of seed-particles from the fiber is not always perfect, and frequently these particles make their appearance in gray calico in the form of black specks or motes, and as they contain small quantities of oil and tannin matters which are pressed out into the surrounding fibers, they cause specks and unevenness in dyeing and finishing. If they come in contact with solutions or materials containing iron compounds, a violet stain will be produced, the color of which, however, may not develop for some months.

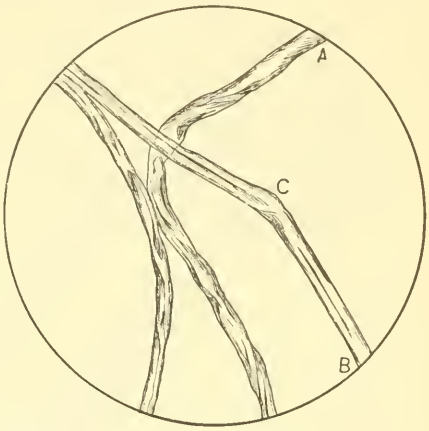


Fig. 166.—Typical Cotton Fibers. (×300.) *A*, Normal fiber showing regular twists; *B*, straight fiber without twists; *C*, a knot or irregularity in growth of fiber. (Micrograph by author.)

6. Physiology of Cotton Fiber.—The development of the cotton fiber from the seed is as follows: "If a very immature cotton boll be cut transversely, the cut section will show that it is divided by longitudinal walls into three or more divisions, and the seeds will be shown attached to the inner angle of each division. The seeds retain this attachment until they have nearly reached their mature size and the growth of lint has begun on them, when their attachments begin to be absorbed, and by the increased growth of the lint the seeds are forced into the center of the cavity. The development of the fiber commences at the end of the seed farthest from its attachment and gradually spreads over the seed as the process of growth continues. The first appearance of the cotton fiber occurs a considerable time before the seed has attained its full growth and commences by the development of cells from the surface of the seed. These cells seem to have their origin in the second layer of cellular tissue, and force themselves through the epidermal layer, which seems to be gradually absorbed. The cells which originate the fiber are characterised by the thickness of their cell-walls when compared with their diameter."[1]

[1] *Bulletin*, No. 33.

Bowman gives an excellent description of the physiological development of the cotton fiber, from which the following is quoted: "In their earliest stages the young cotton fibers appear to have a circular section arising from the comparative thickness of the tube-walls; but as these walls gradually become thinner by the longitudinal growth of the hair and the pressure to which they are subjected by the contact of surrounding fibers enclosed within the pod, they gradually become flattened, and just before the pod bursts the outer walls of the cells have become so attenuated in the longest fibers as to be almost invisible even under high microscopic powers, and present the appearance of a thin, pellucid, transparent ribbon. With the bursting of the pod, however, a change occurs. The admission of air and sunlight causes a gradual unfolding of the hairy plexus, and the rapid consolidation of the liquid cell-contents on the inner surface of the cell-wall gives them a greater thickness and density, which is further increased by the gradual shrinking in of the walls themselves upon the cell-contents. There is also a gradual rounding and thickening of the fiber, which increases by the deposition of matter on the inner wall of the cell. As this action is not perfectly uniform, arising from the unequal exposure of different parts of the fibers to light and air, it causes a twisting of the hairs, which is always a characteristic of cotton when viewed under the microscope, and the flat collapsed portions of the tube form so many reflecting surfaces, to which the brightness of the fiber when stretched tight in the fingers is no doubt due. Another change also occurs at this stage, a change which corresponds to the ripening of fruit. In the earliest period of their formation the growing cells are filled with juices which are more or less astringent in character. Under the influence of light and air these cell-contents undergo a chemical change, in which the astringent principles are replaced by more or less saccharine or neutral juices, until in the perfectly ripe cotton fiber the cell-walls are composed of almost pure cellulose."

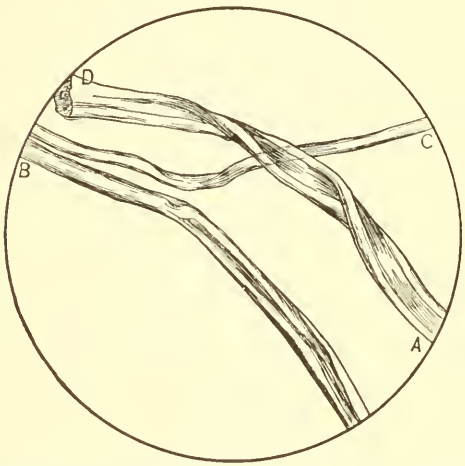


FIG. 167.—Typical Cotton Fibers. (×300.) *A*, Broad flat fiber near base; *B*, thick rounded fiber; *C*, fiber near pointed end; *D*, cut end of fiber. (Micrograph by author.)

Flatters[1] gives a detailed description of the physiology of the cotton

[1] *The Cotton Plant*, p. 59. A very complete description of the physiology of the entire cotton plant is also given in this book, see pp. 17, *et seq.*

fiber, from which the following is adapted: Soon after the fertilisation of the ovum of the flower certain structural differences begin to appear in the cuticle cells forming the wall of the ovary. A thin layer of protoplasm is soon formed around the inner wall of the cell. Intervening cells begin to elongate until the entire surface of the ovule presents the appearance of being covered with minute protuberances. These continue to elongate until a definite fibril covering is attained. At the commencement of this cuticular differentiation the underlying tissue is gorged with protoplasm, in which food substances are imbedded, but which soon become absorbed by the developing fibers. This fibril development is coincident with the formation and development of the embryo, and serves as a protective covering for it. In addition to the protoplasm and nucleus there are found in the cotton fiber during its development and its maturity minute microscopic bodies, the *endochrome*. The presence of the endochrome is more emphasised in wild cottons than in the cultivated species. On this account the fiber of nearly all wild cotton plants has a deep rusty tint (*Khaki* or red cotton). Watt [1] states that so very constant is this peculiarity of the uncultivated cottons, that its appearance in the field may be accepted as an almost certain sign of a low-grade plant, or of defective cultivation, or unsuitable environment. It is in all probability a sign of "reversion" to an ancestral and presumably hardier or more prepotent condition. The presence or absence of the endochrome determines the color of the fiber, which in some types becomes definite by imparting to it a deep brown color, as in "brown Egyptian," and a still deeper color, as in "red Peruvian." Endochrome is found more or less in every class of cotton. It does not, except in a few cases, permeate the cell-wall of the fiber, but becomes coagulated as the fiber matures, and forms a central core in the fibril cavity. It is this core which imparts to the fiber its color by reflection through the transparent cell-wall.

Flatters concludes that the cotton fiber is made up of three primary elements, (*a*) the cuticular envelope; (*b*) the secondary deposit of cellulose; (*c*) the endochromic coloring matter.

The cell-wall of the cotton is thin in comparison with that of the bast fibers, but in comparison with the other seed-hairs it is remarkably thick. This accounts for its much greater strength over the latter. In completely developed fibers the thickness of the cell-wall is from one-third to two-thirds of the total thickness of the fiber itself.

7. Conditions Affecting Quality of Fiber.—The quality of the cotton fiber depends not only on the species of the plant from which it is derived, but also on the manner of its cultivation. The conditions which exercise, perhaps, the greatest influence are: (*a*) the seed, (*b*) the soil, (*c*) the mode of cultivation, (*d*) the climatic conditions. The seed for sowing must

[1] *Wild and Cultivated Cotton Plants*, p. 28.

be carefully and specially chosen for the purpose. A very dry soil produces harsh and brittle cotton, the fibers of which are very irregular in length; a moist and sandy soil produces a very desirable cotton of long and fine staple. The best soil is considered to be a light loam, while a damp clay is regarded as the worst. An excess of rain causes the plant itself to grow too rapidly and luxuriantly at the expense of the fruit and consequently there is less fiber produced. A long drought causes a stunted growth of the plant, but few bolls are produced, and these ripen prematurely. Soils situated in proximity to the sea, and therefore containing considerable saline matter, appear to furnish the most valuable varieties of cotton, and it is claimed that the saline constituents of the soil have considerable influence on the growth and development of the cotton fiber. It is said that the best average daily temperature for the growth of cotton is from 60° to 68° F. for the period from germination to flowering, and from 68° to 78° F. from flowering to maturity. According to Dr. Wight,[1] for the proper maturing of the best qualities of American cotton an increasing temperature during the period of greatest growth is required; the failure to produce in India a quality of fiber equal to the American product from the same kind of seed is attributed to the fact that in the climate of the former country there exists a diminishing rather than an increasing average daily temperature. Flatters states that a humid temperature ranging from 70° upward, and a soil of a deep loamy nature in which alkaline and calcareous salts are present, and which contains at least 3 percent of phosphoric acid, seem to be the most suitable conditions for the successful cultivation of the cotton plant.

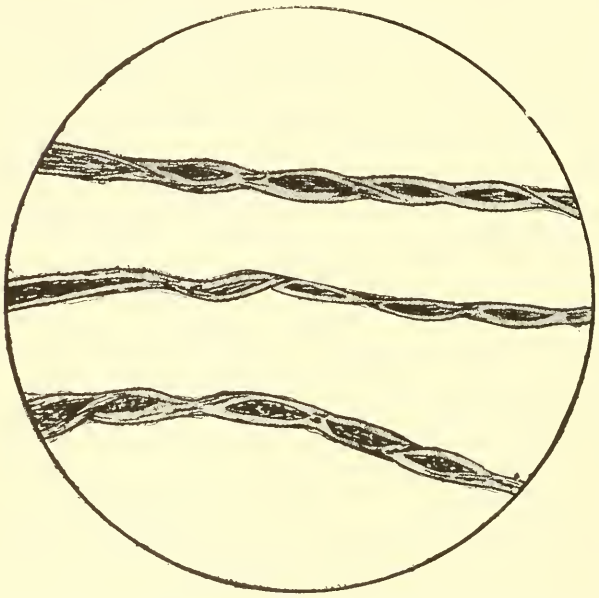


Fig. 168.—Sea-island Cotton. (×400.) (Micrograph by author.)

[1] *Jour. Agr. Hort. Soc. India*, vol. 7, p. 23.

8. Botanical Classification of Cotton.—The classification of the different species of cotton plant varies with different authorities; the most comprehensive, perhaps, is to classify the different varieties of the cotton plant as (1) the tree, (2) the shrub, and (3) the herbaceous species.

The following is a list of species of the cotton plant more or less recognised by botanists:

Gossypium album Hamilton, a synonym of *G. herbaceum;* commercially known as upland cotton; has a white seed.

G. arboreum Linn., a tree-like plant; perennial; indigenous to India; produces but little fiber.

G. barbadense Linn., indigenous to America and outlying islands; gives the highly prized sea-island cotton.

G. brasiliense Macfad., a tropical species; belongs to the so-called "kidney cottons"; the seeds adhere to one another in clusters.

G. chinense Fisch & Otto, a synonym for *G. herbaccum;* a Chinese cotton.

G. croceum Hamilton, a synonym for *G. herbaceum;* possesses a yellow lint.

G. eglandulosum Cav., a synonym for *G. herbaceum.*

G. elatum Salisb., a synonym for *G. herbaceum.*

G. fructescens Lasteyr., a synonym for *G. barbadense.*

G. fuscum Roxb., a synonym for *G. barbadense.*

G. glabrum Lam., a synonym for *G. barbadense.*

G. glandulosum Steud., a synonym for *G. herbaceum.*

G. herbaccum Linn., usually considered of Asiatic origin; synonymous with *G. hirsutum;* ordinary upland cotton.

G. hirsutum Linn., of American origin; Georgia upland cotton.

G. indicum Lam., a synonym for *G. herbaceum.*

G. jamaicense Macfad., a synonym for *G. barbadense;* grows in Jamaica.

G. javanicum Blume, a synonym for *G. barbadense;* grows in Java.

G. kirkii Masters, a wild African species never found under cultivation; the only known variety of which the seed is left quite naked by removal of the fibers.

G. latifolium Murr., a synonym for *G. herbaceum.*

G. leoninum Medic., a synonym for *G. herbaceum.*

G. macedonicum Murr., a synonym for *G. herbaceum.*

G. maritimum Tod., a synonym for *G. barbadense.*

G. micranthum Cav., a synonym for *G. herbaceum.*

G. molle Mauri, a synonym for *G. herbaceum.*

G. nanking Meyen, a synonym for. *G. herbaceum.*

G. neglectum Tod., indigenous to India; similar to *G. arboreum;* extensively grown in India; gives the Dacca and China cottons.

G. nigrum Hamilton, a synonym for *G. barbadense.*

G. obtusifolium Roxb., a synonym for *G. herbaceum,* a distinctly Oriental species to be met with in India, Ceylon, etc.

G. oligospermum Macfad., a synonym for *G. barbadense.*

G. paniculatum Blanco, a synonym for *G. herbaceum.*

G. perenne Blanco, a synonym for *G. barbadense.*

G. peruvianum Cav., a synonym for *G. barbadense.*

G. punctatum Schum. & Thonn., a synonym for *G. barbadense.*

G. racemosum Poir, a synonym for *G. barbadense.*

G. religiosum Par., a synonym for *G. arboreum;* so called because its use is mostly restricted to making turbans for Indian priests; also because it grows in the

gardens of the temples; it has the cultural name of Nurma or Deo cotton. Also a variety of *G. barbadense.*

G. roxburghianum Tod., a variety of *G. neglectum;* corresponds to the Dacca cotton of India.

G. siamense Tenore, a synonym for *G. herbaceum.*

G. sinense Fisch., a synonym for *G. herbaceum.*

G. stocksii Masters, a synonym for *G. herbaceum;* claimed to be the original of all cultivated forms of this latter species.

G. strictum Medic., a synonym for *G. herbaceum.*

G. tomentosum Nutt, indigenous to the Hawaiian Islands where it is known as Mao or Huluhulu cotton; the bark is used for making twine.

G. tricuspidatum Lam., a synonym for *G. herbaceum.*

G. vitifolium Lam., a synonym for *G. barbadense.*

G. vitifolium Roxb., a synonym for *G. herbaceum.*

G. wightianum Tod., a synonym for *G. herbaceum;* claimed by Todaro to be the primitive form of the Indian cottons. It furnishes the so-called long-stapled or gujarat cotton of India.

According to Parlatore all commercial cotton is derived from seven species of the *Gossypium,* which he enumerates as follows:

(1) *G. barbadense* which comprises the long-stapled and silky-fibered cottons known as *Barbadoes, Sea-island, Egyptian,* and *Peruvian.*[1]

The plant reaches a height of from 6 to 8 ft., and has yellow blossoms becoming purple toward the base. The seeds are small in size and of a

[1] The botany of this species is given as follows: Shrubby, perennial, 6 to 8 ft. high, but in cultivation herbaceous and annual or biennial, 3 to 4 ft. high, glabrous, dotted with more or less prominent black glands. Stems erect, terete branching. Branches graceful, spreading, subpyramidal, somewhat angular, ascending, at length recurving. Leaves alternate, petiolate, as long as the petioles, rotund, ovate, subcordate, 3- to 5-lobed, sometimes with some of the upper and lower leaves entire, cordate, ovate, acuminate; lobes ovate, ovate-lanceolate, acute or acuminate, channeled above, sinus subrotund, above green, lighter on the veins, glabrous, beneath pale green and glabrous, 3- to 5-veined, the mid-vein and sometimes one or both pairs of lateral veins bearing a dark-green gland near their bases. Stipules erect or spreading, curved, lanceolate-acuminate, entire or somewhat laciniate. Peduncles equal to or shorter than the petiole, erect, elongating after flowering, rather thick, angled, sometimes bearing a large oval gland below the involucre. Involucre 3-parted, erect, segments spreading at top, many veined, broadly cordate-ovate, exceeding half the length of the corolla, 9 to 12 divided at top, divisions lanceolate-acuminate. Calyx much shorter than the involucre, bracts cup-shaped, slightly 5-toothed or entire. Corolla longer than the bracts. Petals open, but not widely expanding after flowering, broadly obovate, obtuse, crenate, or undulate margined, yellow or sulfur colored, with a purple spot on the claw, all becoming purplish in age. Stamen about half the length of the corolla, the tube naked below, anther bearing above. Style equal to or exceeding the stamens, 3- to 5-parted. Ovary ovate, acute, glandular, 3-, rarely 4- to 5-celled. Capsule a little longer than the persistent involucre, oval, acuminate, green, shining, 3-, rarely 4- to 5-valved. Valves oblong or ovate-oblong, acuminate, the points widely spreading. Seeds 6 to 9 in each cell, obovate, narrowed at base, black. Fiber white, 3 to 4 or more times the length of the seed, silky, easily separable from the seed. Cotyledons yellowish, glandular, punctate.

black color, and are particularly distinguished from those of ordinary American cotton in that they do not possess a fine undergrowth of short hairs (neps); consequently when ginned the seed comes out clean and smooth. Owing to variations in the conditions of its cultivation, however, the present Sea-island cotton has changed considerably from the original *barbadense*. The following species are considered as synonyms of *G. barbadense: G. fructescens* Lasteyr., *G. fuscum* Roxb., *G. glabrium* Lam., *G. jamaicense* Macfad., *G. javanicum* Blume, *C. maritimum* Todaro,

FIG. 169.—Cotton Boll and Leaf, *Gossypium Barbadense*. (Watt.)

G. nigrum Ham., *G. oligospermum* Macfad., *G. perenne* Blanco, *G. peruvianum* Cav., *G. punctatum* Schum. & Thonn., *G. racemosum* Poir., *G. religiosum* Par., and *G. vitigolium* Roxb.

Georgia uplands or *boweds* cotton is presumably a variety of this species modified by cultivation on the mainland. This variety is employed especially for the spinning of fine yarns. *Pima* cotton is a long stapled variety grown in the Salt River Valley and the Yuma Valley of Arizona. It is cultivated especially for use in tire fabrics.

(2) *G. herbaceum*, including most of the cotton from India, southern Asia, China, and Italy.[1] Parlatore claims that this species originated in India, while Todaro says that it is spontaneous in Asia and perhaps also in Egypt, and that *G. wightianum* is the primitive form of the Indian cottons; others still consider it as a native of Africa. According to *Bulletin* No. 33 (U. S. Dept. Agric.), it is probable that *G. herbaceum* is not a definite species, but has been developed by cultivation from perhaps several wild species, and it represents not a species but a group of hybrids and forms more or less closely related. The following species are considered as synonyms of *G. herbaceum: G. album* Ham., *G. chinense* Fisch., *G. croceum* Ham., *G. eglandulosum* Cav., *G. elatum* Salis., *G. glandulosum* Steud., *G. hirsutum* Linn., *G. indicum* Lam., *G. latifolium* Murr., *G. leoninum* Medic., *G. macedonicum* Murr., *G. micranthum* Cav., *G. molle* Mauri, *G. nanking* Meyen, *G. obtusifolium* Roxb., *G. paniculatum* Blanco, *G. punctatum* Guil., *G. religiosum* Linn., *G. siamense* Tenore, *G. sinense* Fisch., *G. strictum* Medic., *G. tricuspidatum* Lam., and *G. vitifolium* Roxb.

The *herbaceum* is an annual plant growing from 5 to 6 ft. in height; unlike the *barbadense* variety, its seeds are generally covered with a soft undergrowth of fine down which is an objectionable feature. The flower is yellow in color with a purplish spot at the base. This species is perhaps

[1] The descriptive botany of this species is as follows: Shrubby, perennial, but in cultivation herbaceous, annual or biennial. Pubescence variable, part being long, simple or stellate, horizontal or spreading, sometimes short, stellate, abundant, or the plants may be hirsute, silky, or all pubescence may be more or less wanting, the plants being glabrous or nearly so. Glands more or less prominent. Stems terete, or somewhat angular above, branching. Branches spreading or erect. Leaves alternate, petioled, the petioles about equaling the blades, cordate or subcordate, 3- to 5-, rarely 7-lobed. Lobes from oval to ovate, acuminate, pale green above, lighter beneath, more or less hairy on the vein, 3- to 5- or 7-veined, the midvein and sometimes the nearest lateral veins glandular toward the base or glands wanting. Sinus obtuse. Lower leaves sometimes cordate, acuminate, entire, or slightly lobed. Stipules erect or spreading, ovate-lanceolate to linear-lanceolate, acuminate, entire, or occasionally somewhat dentate. Peduncles erect in flower, becoming pendulous in fruit. Involucre 3-, rarely 4-parted, shorter than the corolla, appressed, spreading in fruit, broadly cordate, incisely serrate, the divisions lanceolate-acuminate, entire or sometimes sparingly dentate. Calyx less than half the length of the involucre cup-shaped, dentate, with short teeth. Petals erect, spreading obovate or cuneate, obtuse or emarginate, curled or crenulate, white or pale yellow, usually with a purple spot near the base, in age becoming reddish. Stamens half the length of the corolla. Pistil equal or longer than the stamens. Ovary rounded obtuse or acute, glandular, 3- to 5-celled. Style about twice the length of the ovary, 3- to 5-parted above, the glandular portion often marked with 2 rows of glands. Capsule erect, globose or ovate, obtuse or acuminate, mucronate, pale green, 3- to 5-celled. Valves ovate to oblong, with spreading tips. Seed 5 to 11 in each cell, free, obovate to subglabrous, narrowed at base, clothed with two forms of fiber, one short and dense, closely enveloping the seed, the other 2 to 3 times the length of the seed, white, silky, and separating with some difficulty. Cotyledons somewhat glandular punctate.

the hardiest of the cottons and is cultivated over a wider range of latitude. It forms the source of nearly all the Indian cotton, as well as the buff-colored Nankin cotton of China, and the short-stapled varieties of Egyptian and Smyrna cottons. It is used for the spinning of low-count yarns, also for the making of condenser yarns for the manufacture of flannelettes.

FIG. 170.—*Gossypium Herbaceum.* (Watt.)

Todaro claims that the species *G. wightianum* is the form chiefly cultivated in India. It differs from the general form of *G. herbaceum* in that the latter has broader and more rounded leaves, and broader, thinner, and deeper cut bracteoles.[1]

There is another very similar form indigenous to India known as *G. neglectum;* it grows as a large bush, and its fiber constitutes the majority of the commercial Bengal cotton.[2]

[1] The botany of *G. wightianum* is as follows: Stems erect, somewhat hairy, branches spreading and ascending. Leaves, when young, densely covered with short thick, stellate hairs, becoming nearly glabrate in age; ovate-rotund, scarcely cordate, 3- to 5-, rarely 7-lobed; lobes ovate, oblong, acute, constricted at base into a rounded sinus. Stipules on the peduncles almost ovate, others linear-lanceolate, acuminate. Flowers yellow with a deep purple spot at base, becoming reddish on the outside in age. Bracteoles small, slightly united at base, ovate, cordate, acute, shortly toothed. Peduncles erect in flower, recurved in fruit, one-quarter, the length of the petioles. Capsule small, ovate, acute, 4-celled, with 8 seeds in each cell. Seeds small, ovate, subrotund, clothed with two forms of fiber, the inner short and closely adhering, the other longer, white or reddish.

[2] Its botany is as follows: Stem erect. Branches slender, graceful spreading.

Notwithstanding the inferiority of Indian to American cotton, the Dacca spinners can to-day produce from what is considered a very poor cotton staple a yarn quite as fine as that made in England and America from the finest and best staples. This remains one of the enigmas of the cotton industry, and it would seem that the hand spinners can accomplish something the machine spinners cannot.

Fig. 171.—American Cotton; *G. hirsutum*. (Watt.)

The cultivated cottons of to-day are far different from the original form of the *G. herbaceum*, which gave only 28 to 29 percent of fiber, with a staple 20 to 200 mm. long. The proportion of fiber has been greatly increased, reaching as high as 36 and even 40 percent in some varieties, while the length of staple has increased correspondingly, sometimes reaching fully three times its original length.

Leaves, lower ones 5 to 7 palmately lobed, segments lanceolate, acute, rarely bristle-tipped, sinus rounded, the small lobes in the sinuses less distinct than in *G. arboreum*, upper leaves, 3-parted. Stipules next the peduncles semiovate, dentate, the others linear-lanceolate, acute. Peduncles, with short lateral branches, 2 to 4 flowered. Involucral bracts coalescent at base, deeply and acutely laciniate. Petals less than twice the length of the involucral bracts, obovate, unequally cuneate, yellow, with a deep purple spot at base. Stamen-tube half the length of the corolla, naked at base. Capsule small, ovate, acute, cells 5- to 8-seeded, seed obovate, small, clothed with two forms of fiber, one very short, closely adherent, and of an ashy green color, the other longer, rather harsh, white.

The *vine cotton* of Cuba belongs to the *G. herbaceum* species, and is peculiar because of its large pods and excessive number of seeds.

(3) *G. hirsutum*, including most of the cotton from the southern United States also known as *upland* or *peeler* cotton. American or mainland cotton is the typical cotton of the world. It is grown in the American cotton belt which extends from southeast Virginia to Texas. This cotton is suited for all numbers of yarn up to 50's warp and 80's filling, being clean, regular in length of staple and well graded. On account of these features, as well as the fact that the quantity raised is greater than all the other cotton of the world, the price of American cotton regulates the price of cotton throughout the world. Of this American cotton, the Gulf (New Orleans), Benders, or Bottom Land varieties are the most important, varying in length from 1 to $1\frac{3}{8}$ ins. Cotton sold in the market as Mobile, Peelers, and Allen-seed belong to the same variety and are next in importance; while Mississippi, Louisiana, Selina, Arkansas, and Memphis cottons are slightly inferior. Texas cotton varies from $\frac{7}{8}$ to 1 in. in length and is suitable for warp yarns up to 32's. Next in importance is the upland cotton, having a length of $\frac{3}{4}$ to 1 in. and suitable for spinning into 30's filling. Cottons sold under the names of Georgia, Boweds, Norfolk, and Savannah also belong to the upland variety.

FIG. 172.—Tree Cotton; *G. arboreum*. (Watt.)

The cotton plant of the Southern States is a small annual shrub from

2 to 4 ft. in height, always branching extensively. The limbs are longest at the bottom of the stalk, and short and light at the top. The flowers are white or pale yellow or cream-colored the first day, becoming darker and redder the second day, and fall to the ground on the third or fourth day, leaving a tiny boll developed in the calyx. This boll enlarges until maturity when it is not unlike the size and shape of a hen's egg. When matured, the boll cracks and opens the three to six compartments which hold the seed and the lint.

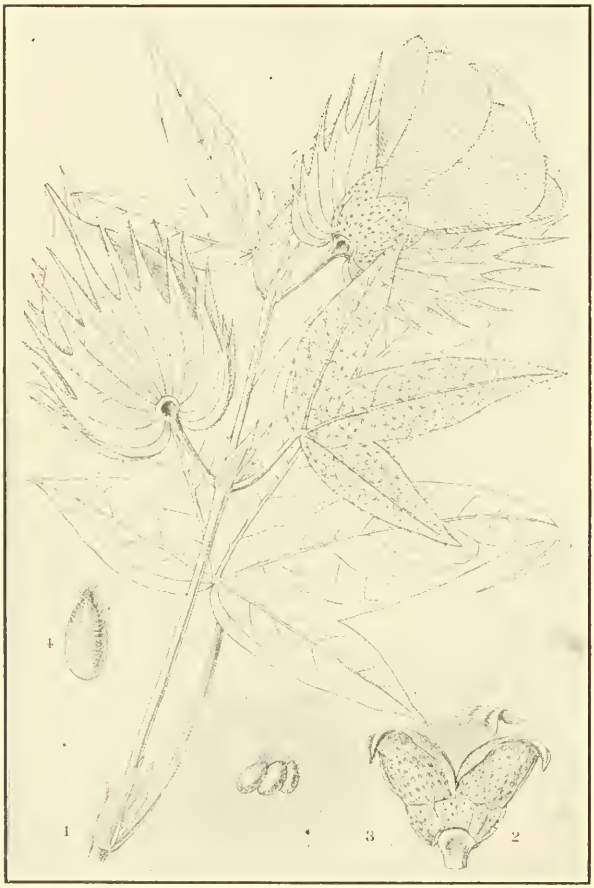


FIG. 173.—Red Peruvian Cotton; *G. microcarpum*. (Watt.)

The plant of *G. hirsutum* is shrubby in appearance, seldom reaching more than 7 ft. in height; like the preceding variety, the seeds are also covered with a fine undergrowth of down. The flower is either yellowish white or of a faint primrose tint.

Todaro claims that this species originated in Mexico, whence it has been spread by cultivation throughout the warmer portions of the world; to this form he also ascribes the Georgia or long-stapled upland cotton. Parlatore, on the other hand, considers it as indigenous to the islands in the Gulf of Mexico as well as the mainland, and that all green-seeded cotton, wherever cultivated, originated from this form. Under cultivation this plant varies in many directions. It is usually a coarse, stunted, much-branched, erect, greenish red, dust-coated bush (this peculiarity being a consequence of the abundance, length, and strength of the hairs with which the leaf stalks, etc., are covered). The leaves rapidly lose the habit of being entire, and are mostly 3-lobed, or as a result of luxuriant

cultivation, become partially lobed. The flowers range from small pale yellow to large and yellow with a purplish tinge. The fruit is usually 4-celled, and the seeds always large, ovate, truncate on one extremity, and with a pronounced fuzz, which may be grayish, rusty or green in color.[1]

(4) *G. arboreum*, including the cotton from Ceylon, Arabia, etc.[2] As the name indicates, it is a treelike plant, and grows from 12 to 18 ft. in height. The fibers are of a greenish color and very coarse; its flowers are of a purple color. A synonym of this species is *G. religiosum;* it appears to be indigenous to India. The plant is perennial and lasts from five to six years, and though the fiber is fine, silky, and of good length, yet there is but little

FIG. 174.—Tahiti Cotton; *G. Tahitense.* (Watt).

[1] Watt, *Wild and Cultivated Cottons*, pp. 183, 184.

[2] The descriptive botany of this species is as follows: Shrubby, perennial, but in cultivation sometimes annual or biennial; tomentose, with two forms of hairs, one long and simple, the other more numerous, shorter, and stellate; glands small, scarcely prominent, more or less scattered. Stem erect, terete, very branching. Branches spreading, terete. Leaves alternate, petiolate, with petioles a little shorter than the blade, subcordate, 5- to 7-lobed, lobes oblong-lanceolate or lanceolate-acuminate, bristle-tipped, scarcely channeled above; sinus obtuse, often with a small lobe in some of the sinuses, beneath pale green and softly pubescent, 5- to 7-veined, the mid-vein and often the two adjacent ones with a reddish-yellow gland near their base; upper leaves palmately 3- to 5- lobed, lobes short. Stipules erect, spreading, lanceolate-acuminate. Peduncles axillary, erect before and spreading or horizontal after flowering and drooping

of it produced. No varieties of this species are grown in America for commercial purposes, and not even in India, where it is principally cultivated, is it a very valuable type of cotton; it is never used as a field crop. It is commonly known as *tree cotton* or *cotton tree*. In India its cultivation is probably more ancient than that of any other cotton.

(5) *G. peruvianum*, including the native Peruvian and Brazilian cottons. This differs from other varieties of cotton in that it is a perennial plant; the growth from the second and third years, only, however, is utilised.

(6) *G. tahitense*, found chiefly in Tahiti and other Pacific islands.

(7) *G. sandwichense*, occurring principally in the Hawaiian Islands.

This classification is claimed to include all the commercial varieties of cotton; it is probable, however, that the last two can be included under the *barbadense* and *hirsutum* varieties, as they possess the same characteristics as these fibers.

Dr. Royle reduces the number of species of the cotton plant to the following four:

(1) *Gossypium arboreum.*
(2) " *herbaceum.*
(3) " *barbadense.*
(4) " *hirsutum.*

Other authorities on the botany of the cotton plant have recognised many more species than those above described. Agostino Todaro has described 52 varieties, while the *Index Kewensis* records 42 distinct species and refers to 88 others which it classifies as synonyms. Hamilton reduces the number of species to three—namely, the white-seeded, black-seeded, and yellow-linted, assigning to these species the botanical names *album*, *nigrum*, and *croceum*. The chief difficulty experienced in the botanical classification of the cotton plant is the fact that it hybridises very readily and has a tendency to suffer alteration in variety with change

in fruit, about three-fourths the length of the petioles, terete, destitute of glands, 1 to 2 usually 1-flowered, jointed above the middle, bearing a small leaf and two stipules at this point. Involucre 3-parted, appressed or scarcely spreading at summit, many nerved, broadly and deeply cordate, ovate-acuminate, 5 to 9, rarely 3 dentate or nearly entire. Calyx much shorter than the bracts, subglobose, truncate, crenulate or subdentate, with a large gland at the base within the involucre. Corolla campanulate, petals erect, or spreading broadly cuneate, subtruncate, crisp or crenulate, purple or rose-colored, with a large dark purple spot at the base. Staminal tube about half the length of the corolla. Pistils equally or a little longer than the stamens. Ovary ovate, acute, glandular, usually 3-celled. Style a little longer than the ovary, 3-parted without glands. Capsule pendulous, a little longer than the persistent involucre, ovate, rounded, glandular, 3- to 4-celled, and valved. Valves ovate, oval, spreading, mucronate-acuminate, the mucro recurved. Seed 5 to 6, ovate, obscurely angled, black. Fiber two forms, one white, long, overlying a dark green or black down; not readily separable from the seed.

in the conditions of its cultivation or variation in the character of the soil or climate. The following remarks relative to the subject of the cross-fertilisation of cotton are given in *Bulletin* No. 33 (*vide supra*). The flower of the cotton plant is so large and develops so rapidly that cross-fertilisation is easily secured. Flowers which are to be fertilised should be among those which are developed early in the season, and should always be those on healthy and vigorous plants. The flowers to be operated upon should be selected late in the afternoon; one side of the unopened bud should be split lengthwise with a sharp knife having a slender blade, and the stamens removed. The anthers, the fertilising parts of the stamens, will be found well developed and standing well away from the pistil, though not yet so matured as to be discharging pollen. These can be readily separated from their support by a few careful strokes of the knife, and the emasculated flower should then be enclosed in a paper bag to prevent access of pollen from unknown sources. The following morning the pistil will be fully developed and ready to receive pollen. A freshly opened flower from a healthy plant of the variety which it is desired to use in making the cross is picked and carried to the plant which was treated the previous evening, the bag is removed from the prepared flower, and by means of a camel's-hair brush pollen is dusted over the end and upper part of the pistil. The paper bag is then replaced and allowed to remain two days, after which it should be removed.

In Europe cottons are graded according to their value as follows:

1. Long Georgia.	4. Louisiana.	7. Short Georgia.
2. Makko.	5. Cayenne.	8. Surat.
3. Pernambuco.	6. New Orleans.	9. Bengal.

Besides the varieties of cotton above enumerated, which are practically all which find any important commercial application, there is another plant which yields a fiber somewhat similar to cotton, and known as the silk-cotton plant. It belongs to the same natural order, *Malvaceæ*, as the ordinary cotton plant, but is of a different genus, being *Salmalia* instead of *Gossypium*. It grows principally on the African coast and in some parts of tropical Asia. The plant is rather a large tree, reaching from 70 to 80 ft. in height. The blossoms are red in color, and the seeds are covered with long silky fibers, which are not adapted, however, for spinning.

9. Commercial Varieties of Cotton.—Although fibers from the different special of the cotton plant all possess the same general physical appearance, nevertheless, there are characteristic features in each worthy of careful observation. Though to the casual observer the different varieties of cotton fiber look more or less alike, there is nevertheless great differences in qualities and properties, and these must be carefully recognised by the

manufacturer who must select and grade his stock with reference to the nature of the yarn he is to spin. It requires a highly trained and experienced judge to properly grade the different qualities of cotton for manufacturing purposes, and though the greater part of this skill is acquired through intimate contact with actual manufacturing conditions, yet great aid may be had through the use of the microscope in scientifically studying the structure of the cotton fiber.

10. Sea-island Cotton.—This constitutes the most valuable, perhaps, of all the different species.[1] Its chief points of superiority are (*a*) its length, being more than half an inch longer than the average of other cottons; (*b*) its fineness of staple; (*c*) its strength; (*d*) its number and

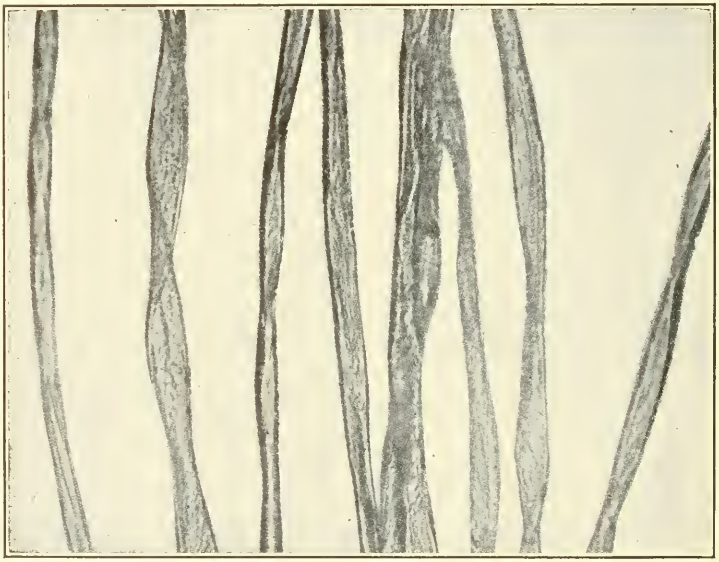


FIG. 175.—Sea-island Cotton.

uniformity of twists, which allow it to be spun to finer yarns; (*e*) its appearance, it being quite soft and silky. It is also characterised by a light-cream color. Sea-island cotton is mostly used for the production of fine yarns ranging from 120's to 300's; it is said that as fine as 2000's [2]

[1] Sea-island cotton is the most valuable of all varieties of cotton. It is of particular importance in the lace industry and in the automobile tire industry. Unfortunately, the crop appears to be steadily declining in quantity, largely because of the ravages of the boll-weevil. In 1917 the United States crop amounted to 92,619 bales, or 35,990,000 lbs.

[2] See Monie, *Structure of the Cotton Fiber*, p. 40, as authority for this statement. A thread of such fineness would not be commercial, and has never been prepared, except, perhaps, in an experimental manner.

has been spun from it. The " count " of cotton yarn means the number of hanks of 840 yards each contained in 1 lb. The size 120's, for instance, means cotton yarn of such fineness that 120 hanks of 840 yds. (= 100,800 yds.) weight 1 lb. On account of its adaptability for mercerising Sea-island is also largely employed for this purpose, in which case much coarser yarns are often prepared from it.

Some writers claim that Sea-island cotton is peculiarly of American origin; that it was found on the island of San Salvador by Columbus, and by him brought to Spain. Other writers, among whom is Masters,[1] assert that this cotton is of central African origin. Sea-island was introduced into the United States in 1786, and was first grown on St. Simons Island off the coast of Georgia. It appears to have been brought from the island of Angulla in the Caribbean Sea to the Bahamas, and from the latter to the coast of Georgia. From St. Simons the plant extended to the Sea Islands of Charleston, where the finest varieties are now grown. Very fine staple is also grown along the coast of East Florida. Sea-island cotton may be cultivated in any region adapted to the olive and near the sea, the principal requisite being a hot and humid atmosphere, but the results of acclimatisation indicate that the humid atmosphere is not entirely necessary if irrigation be employed, as this species is undoubtedly grown extensively in Egypt. As a rule, the quality of the staple increases with the proximity to the sea; but there are exceptions to this rule, as that grown on Jamaica and some islands is of rather low grade, while the best fiber is produced along the shores of Georgia and Carolina.[2] Sea-island requires a great deal more moisture than the upland cottons; in fact, moisture is an all-important factor in the quality of the staple. Dry years give a poor staple and wet years a good staple.

Owing to the wide cultivation of Sea-island cotton at the present time, for its growth is no longer strictly confined to the islands of the sea, it is difficult to make a definite statement as to its length of staple, as this will vary considerably with the method and place of cultivation. The maximum length, however, may be taken as 2 ins., and the minimum as $1\frac{1}{2}$ ins., with a mean of $1\frac{3}{4}$ ins. Sea-island cotton gives a smaller yield of fiber than any variety of cotton grown in America, but, on account of the greater length and fineness of staple, it has a much higher market value. The average yield is about 100 lbs. of lint per acre, and it requires from $3\frac{1}{2}$ to $4\frac{1}{4}$ lbs. of seed to yield 1 lb. of lint. A normal crop for the area in which it is grown is from 90,000 to 110,000 bales, nine-tenths of which is grown in Georgia and Florida. In the limited area in which it is produced probably 500,000 bales could be grown.

Florida Sea-island cotton is very similar in general characteristics to

[1] *Jour. Linn. Soc.*, vol. 19, p. 213.
[2] *Bulletin No.* 33, U. S. Dept. Agric.

Sea-island proper, possessing about the same mean length of staple, but being somewhat less in the maximum length. Both of these varieties of Sea-island show a maximum diameter of 0.000714 in., a minimum of 0.000625 in., and a mean of 0.000635 in.

Fiji Sea-island is less regular in its properties than the two preceding varieties, and though its maximum length is somewhat greater than Sea-island itself, yet the mean length is about the same, as is also the diameter. This cotton, however, has a very irregular staple and contains a large percentage of imperfect fibers, which causes the waste to be rather high. The number of twists in the fiber is also less and does not occur as regularly.

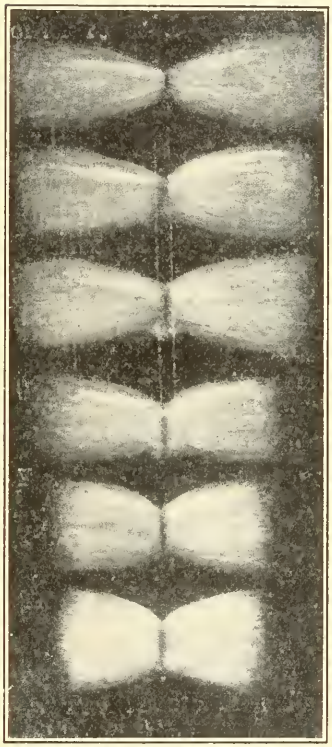


Fig. 176.—Combed Lint from: (1) Sea-island; (2) Egyptian Pima; (3) Meade; (4) Durango; (5) Acala; (6) Lone Star. (Two-thirds Natural Size.)

Gallini Egyptian is Sea-island cotton grown in Egypt. It is somewhat inferior to the American varieties in general properties. It possesses a yellowish color, which distinguishes it from the product of all other countries. Gallini cotton has the bad feature of containing considerable undeveloped and short fiber, and this somewhat lessens its commercial value.

The *Bahmia* variety of Egyptian cotton is a form of Sea-island cotton to which Todaro has given the varietal name of *polycarpum*. It is characterised by numerous flowers springing from a single axil, and an erect, slightly branching habit, hence giving a large yield per acre. It was once thought that the *Bahmia* cotton was a hybrid between okra and cotton, but in a Kew Report (1887, p. 26) this is shown to be incorrect.

Peruvian Sea-island also possesses this same defect, but, in addition, contains usually quite a large amount of foreign matter, such as broken leaf, sand, seed particles, etc. The maximum length of the fiber is $1\frac{5}{8}$ ins., the minimum $1\frac{1}{4}$ ins., and the mean $1\frac{1}{2}$ ins. The fibers differ very little in their diameter, the average being 0.000675 in. Peruvian Sea-island is somewhat coarser in structure than the Sea-island proper, being more hairy in appearance; it has a slight golden tint. In staple it varies from $1\frac{3}{8}$ ins. in length to $1\frac{3}{4}$ ins., with a mean of $1\frac{1}{2}$ ins.

Tahiti Sea-island resembles the Fiji variety very closely; it has a creamy color. The length of staple varies from $1\frac{1}{4}$ to $1\frac{3}{4}$ ins., with a mean of $1\frac{1}{2}$ ins.

It shows a considerable percentage of imperfect fibers due to a short undergrowth on the seed. Its average diameter is 0.000641 in.

11. Egyptian Cotton.—The first variety of cotton to be grown in Egypt was called Makko-Jumel; this went through many changes and evolutions, and gradually changed in color to a yellowish brown, the new variety being known as Ashmouni, from the valley of Ashmoun, where the change was first noticed. The principal varieties of Egyptian now grown are the Mitafifi, Ashmouni, Joanovich, Unbari, Sakellarides, Assili, and Hinde. There may also be mentioned Bahmia, Abassi, and Gallini.[1]

Mitafifi, or Brown Egyptian, is the average quality of Egyptian cotton. It is said to have been developed by a Greek merchant of that name,

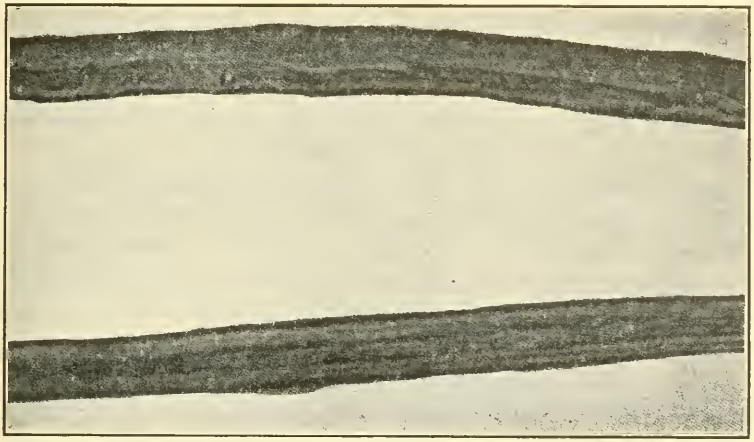


FIG. 177.—Egyptian Cotton.

and it was first grown in 1883, but is now the principal cotton grown in Egypt. Its market price forms the basis for that of the other varieties. The plant is characterised by a bluish green tuft at the extremity of the seed. Its color is richer and darker brown than the Ashmouni. The fiber is long, strong, silky, and fine, and very desirable in the market. The fiber has a staple of about $1\frac{3}{8}$ ins. and is noted for its regularity both with regard to length and color. It was popular on account of its large yield per acre (500 to 600 lbs.), but of late years it has tended to decrease in favor of other varieties of higher grade. The plant is said to withstand drought and attacks from insects better than any other variety. It also requires less attention in picking and gives a better output in ginning.

[1] Many of the Egyptian cottons are hybrids of *G. braziliense*, such as the *Ashmouni*, *Mitafifi*, *Zafiri*, and *Abassi*. It is probable, however, that the *Ashmouni* as described by some writers is *G. microcarpum*.

Ashmouni formerly made up the bulk of the Egyptian crop, but has now been largely superseded by other varieties. It is produced almost exclusively in upper Egypt. Its color is a light brown and its staple is over an inch in length. It is the oldest variety of Egyptian cotton and differs from the other forms in that its seed is clean with no adhering fiber. The Ashmouni, however, is now ranked as one of the poorest of Egyptian cottons. Its yield is relatively small (390 lbs. per acre); and though its length may reach $1\frac{1}{2}$ ins., the fiber is weaker, more irregular and dirtier than the other varieties. It is chiefly used for the spinning of coarse yarns.

Joanovich (or *Yannovitz*) is considered by some to be the best of Egyptian cottons. It is named from the Greek who produced it, being evolved by artificial selection from Mitafifi. The fiber is strong, clean, and silky, and has a length of about $1\frac{1}{2}$ ins. At the present time, however, its use has declined in favor of Sakellarides.

Unbari is a rather recent variety evolved from Mitafifi, but it is not so good as Joanovich, being weaker, darker, and more irregular. Its color, however, is lighter than that of Mitafifi.

Sakellarides was first planted in 1910 and has steadily grown in favor. The fiber is soft, silky, and cream-colored with a fairly reddish tinge. The staple is 1.4 to 1.7 ins. in length. The fiber possesses many characteristics of Sea-island cotton, and in addition the yield per acre is quite high. Its cultivation has steadily increased, and in 1915 over one-half the total Egyptian crop was of this variety.

Assili is a brown cotton similar to Mitafifi. It is apparently an old variety and is said to be indigenous to the country; but it is little cultivated now and is fast disappearing. The fiber is strong and rather regular and there have been attempts made during recent years to bring back its cultivation. It has a fine golden-yellow color and is characterised by toughness and high tensile strength. It is, however, shorter and coarser than Mitafifi, the mean staple being about $1\frac{1}{4}$ ins. in length.

Hinde is an indigenous cotton, found growing wild in Abyssinia at the present time. It has a coarse, white, inferior fiber, about 1 in. in length. It sometimes contaminates fields of Mitafifi.

Bahmia was once cultivated more or les sextensively, but the fiber is rather poor, of a light brown color and not very strong.

Abassi cotton is of rather recent introduction, being first produced in 1891, by a Greek named Parahimona, who named it after the Khedive of Egypt. The fiber is white in color and is known in trade as White Egyptian, being the only white cotton now grown in Egypt. The fiber is longer and more silky than Mitafifi, though not so strong.

Gallini cotton was derived from Sea-island, but did not meet with much success, for though the first year's crop was excellent, succeeding

crops have shown rapid deterioration. It has now almost entirely disappeared from cultivation.

Sultain is a very long and silky variety, resembling Sea-island cotton. It is an expensive cotton to grow and is limited in amount.

Egyptian cotton, as a class, is not so fine as Sea-island, but is better than American upland cotton, that is, for goods requiring a smooth finish and a high luster, the staple being strong and silky.

The fiber of Egyptian cotton is especially adapted to the manufacture of hosiery yarns and yarns for mercerising. The United States imports Egyptian cotton to the value of about $10,000,000 per year. The total annual crop of cotton from Egyptian plantations is from 850,000 to 875,000 bales.

The silky nature of the Egyptian cottons, and the fact that they possess a brown color, probably indicate that they are really of Sea-island origin, but there is no evidence to show whence their deeper coloration than Sea-island arose, unless it was by means of a cross with some highly colored variety such as Peruvian. It has been suggested that the peculiar soil conditions of Egypt may account for the color, but there exists in Egypt a pure white variety, *abassi*, which shows no tendency whatever toward the development of a brown coloration, which seems to preclude this idea.

Egyptian cotton, on account of its long, strong, and silky staple, is especially adapted for sewing-thread, fine underwear, and hosiery, and other goods requiring a smooth finish and high luster. It is interesting to note that yarn of Egyptian cotton is finer than that of the same number made from American cotton. The fibers of the former are narrower, which, combined with their great flexibility, permits of their being closely twisted one with the other, thus making the yarn firmer and more compact.

12. African Cotton.—*African* cottons are all derived from the *herbaceum* species.[1] These cottons have a slight brownish tint, and always contain a large amount of short fibers. The fibers also vary much in diameter and thickness of the tube-walls, and many exhibit a transparent appearance under the microscope. Yarns made from these cottons are always uneven on the surface. The length of staple varies from $\frac{7}{8}$ to $1\frac{1}{8}$ ins., with an average of 1 in.; the mean diameter is 0.00082 in.

Smyrna cotton is grown principally in Asiatic Turkey. It has a rather characteristic appearance under the microscope, being very even in its diameter but irregular in its twist, showing many fibers where the twist is almost entirely absent. In length the staple varies from $\frac{7}{8}$ to $1\frac{1}{8}$ ins., with a mean of 1 in.; the mean diameter is about 0.00077 in.

[1] Watt is of the opinion that *G. herbaceum* proper does not occur in Africa, the chief cultivated African plants being derived from *G. obtusifolium* and *G. nankin*, variations of the foregoing species.

13. Indian Cotton.—*Hingunghat* cottons are Indian varieties; the quality of these varies with the soil and climate of the province in which they are grown. Though India is perhaps the oldest of the cotton-producing countries, its yield if late years has been decreasing. The average

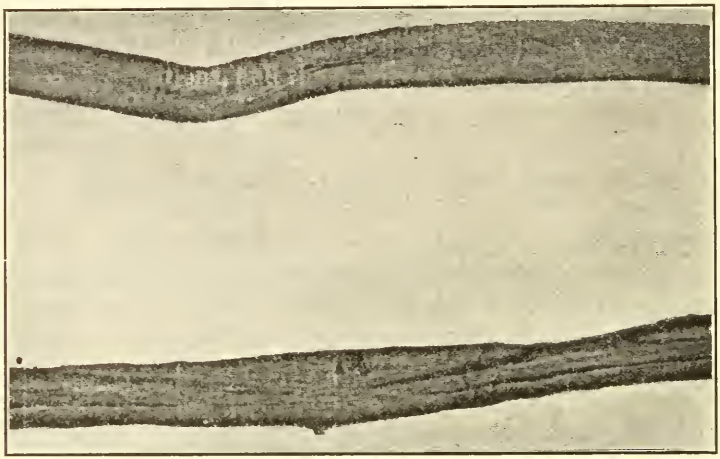


FIG. 178.—African Cotton.

yield per acre is about one-half the average American yield; for though the soil of India is well adapted to cotton growing, the climate is very unfavorable. Indian cotton has a very low yield; in 1917 there were 24,781,000 acres planted in cotton and these furnished only 3,228,800

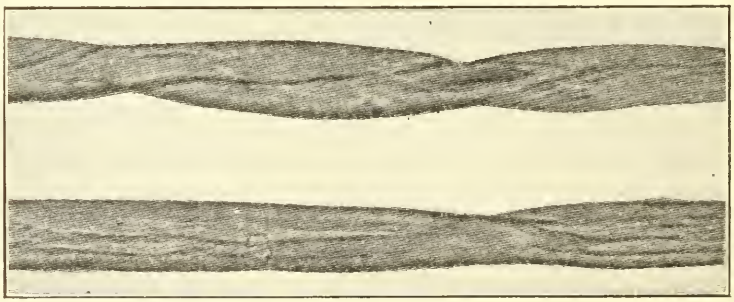


FIG. 179.—Upland Cotton.

bales (500 lbs. each) of fiber, giving an average yield of only 65 lbs. per acre. The corresponding statistics for other cottons for the year 1918 were: American, 37,073,000 acres yielding a crop of 12,500,000 bales, or 170 lbs. per acre; Egyptian, 1,315,572 acres yielding 4,930,000 bales, or 375 lbs. per acre. As a rule, Indian cottons are of rather inferior grade; the best

variety is the *Surat* cotton. The finest sort of cotton from the Orient is known as "Adenos." Under the microscope the Hingunghat cotton shows much variation in diameter, although it possesses fewer twists than the better grades of cotton, yet, unlike the African varieties, it shows very few fibers without any convolutions at all. In length of staple it varies from $\frac{7}{8}$ to $1\frac{1}{8}$ ins., with a mean of 1 in.; the average diameter is 0.00084 in.

Broach, Tinnevelly, Dharwar, Oomrawuttee, Dhollerah, Western Madras, Comptah, Bengal, and *Scinde* are other varieties of Indian cotton, all belonging to the *herbaceum* species. They have the same general properties and staple as the preceding, becoming more and more inferior, however, in the order of the list given. For many years past the Indian cotton trade has been drifting into a restricted groove. The produce goes to mills which do not require a superior or long staple, but one which is uniform. India is thus destroyed as a possible source of supply for the English mills. The Indian mills are at the same time compelled to look to foreign countries for their present or future supplies of superior staples, and are thus more or less confined in their operation to one class of goods.

Caravonica cotton is a new variety produced in Australia, though its cultivation has also been introduced into Egypt and Peru, but in these latter countries the fiber produced is rather inferior. The Caravonica cotton from Australia presents all the characteristics of a good quality fiber; it has a long staple, from 4.5 to 5 cms. and is very even. There are two principal types, a silky fiber and a woolly one. In microscopic appearance and in its microchemical tests Caravonica cotton is very similar to ordinary American cotton, the chief difference being that though the fiber is quite white in color, the points have a yellowish tinge.

14. American Cotton.—*Orleans* or *Gulf* cotton is the typical American variety, and is perhaps the best of the American cottons. The fibers are quite uniform in length, having an average staple of about 1 in. and a mean diameter of 0.00076 in. It is almost pure white in color. As the name indicates, Gulf cotton is grown in the states bordering on the Gulf of Mexico and in the basin of the Mississippi River. In using this name, many in the trade seem to refer to a cotton $1\frac{1}{16}$ in. staple, or something better than the ordinary $\frac{7}{8}$ in. to 1 in. The length of staple, however, does not decide the grade or the regional trade name, for a considerable quantity of $1\frac{1}{16}$ in to $1\frac{1}{8}$ in. cotton is grown in the Upland districts. The general color of Gulf cotton is whiter and the leaf often larger and blacker than that of either Upland or Texas cotton. The word "Gulf" is not much used in the actual buying and selling of cotton, other trade names that have a more definite meaning being employed. The most common of these trade names are Peelers, Benders, Rivers, Canebrake, and Red River, although a number of so-called varieties may be sold under each of these names. "Peelers" was formerly a varietal name, but it is now

applied rather indiscriminately to most of the $1\frac{1}{4}$ in. Mississippi Delta cotton. "Benders" is not a varietal name. It is applied to $1\frac{1}{8}$ in. to $1\frac{3}{16}$ in. cotton of good body that is grown along the Mississippi, Arkansas, and White rivers. The word is said to have applied originally only to cotton that grew in Mississippi, Louisiana, and Arkansas along the bends of the Mississippi River. "Rivers" is used in referring to cotton having a staple of $1\frac{1}{16}$ in. to $1\frac{1}{8}$ in., though if the cotton has a light body it is sometimes called "Creeks." "Canebrake" is the name applied to cotton that is grown in the southcentral part of Alabama on a strip of black prairie land. Most of this cotton has a strong $1\frac{1}{16}$ in. staple, and brings

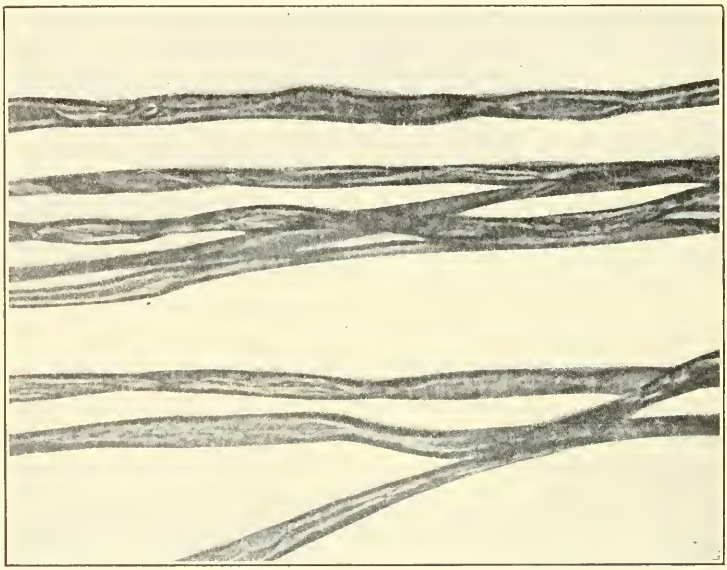


FIG. 180.—Mississippi Delta Cotton.

a higher price than other Alabama cotton. *Texas* cotton much resembles the foregoing, but has a slight golden color; its length and diameter of staple are the same. "Texas" is the trade name given to cotton grown in Texas and Oklahoma. This generally has about the same length of staple as Upland cotton, except in the river basins and black prairie, where the length is usually $1\frac{1}{16}$ in. The character of the fiber of Texas cotton varies considerably from year to year. When the growing season is dry, the fiber is harsher and shorter, while the color may have a reddish tinge. Many of the leaves are dried up early in the picking season by the heat and drought. This, no doubt, accounts for the trash in this cotton being of a brighter color and more broken or peppery than in either the Gulf or Atlantic States cotton. A large quantity of boll hulls, shale

and stalk, is often found in this growth of cotton, and especially in Oklahoma and northern Texas, where all the top crop does not mature, owing to the shorter growing season. These half-opened bolls and the bolls that do not open at all are usually ginned on a " double-rib " huller gin, and the cotton is known in the trade as " bollies." Another type of cotton where the open and mature bolls have been gathered with the burr is found in this section near the end of the picking season. This cotton, although often resembling bollies, has a superior fiber, and may be graded in the usual way. *Upland* cotton is another very similar variety; its length of staple, however, is somewhat less than the foregoing, averaging but $\frac{15}{16}$ in. Its twist is rather inferior to the Orleans, and it shows a larger number of straight fibers. There is considerable difference of opinion among authors when discussing the origin of upland cotton. The weight of opinion seems to be that the species is either *G. herbaceum* or *G. hirsutum*, which many consider synonymous. The origin of this species is much more confused than that of Sea-island cotton. If we would separate the upland cotton into two species, *G. herbaceum* and *G. hirsutum*, probably the question would be simplified, as the former is generally considered of Asiatic origin, while the other is attributed to America.

There are more than a hundred recognised horticultural varieties of upland cotton in cultivation, all belonging to one botanical species, *G. hirsutum*, native to the American tropics. The original wild plants in the tropical zone were perennials, but the plant is cultivated as an annual. The Upland type of cotton constitutes the bulk of the American crop, and is perhaps the most useful cotton grown. It is produced almost throughout the inland districts of the cotton-growing states, but chiefly in North Carolina, South Carolina, Georgia, Alabama, Tennessee, and Virginia. Much cotton that is grown in the hilly parts of Mississippi, Louisiana, and Arkansas is sold as Upland. This cotton averages $\frac{7}{8}$ in. to 1 in. in length, although a number of long-staple varieties up to $1\frac{5}{16}$ in. in length are being successfully grown in the Upland districts. In parts of the Piedmont section the length is very often more than 1 in., while in the sandhills it may be less than $\frac{7}{8}$ in. Cotton grown in the Piedmont section generally has a bright creamy color, or " bloom," that is considered desirable by many spinners. The leaf is usually black and in rather small pieces, while in the cotton from the sandy soil the color is generally whiter and the leaf larger and brighter. *Mobile* cotton is the most inferior of the American varieties; it varies in length of staple from $\frac{3}{4}$ to 1 in., with a mean of $\frac{7}{8}$ in.; its average diameter is 0.00076 in. It shows about the same microscopic appearance as upland cotton.

15. Peruvian and Brazilian Cottons.—*Rough Peruvian* cotton has a light creamy color and is rather harsh and hairy in feel. Peruvian cotton is often called *kidney cotton*, being characterised by the seeds in each lobe

of the capsule clinging together in a compact cluster. These seeds are black and without a persistent fuzzy covering. The lint shows a wide variation in color and texture—white, brown, reddish, rough and harsh, or smooth and soft. Most of it has a shorter, coarser, and more wiry fiber than that of American upland. The lint of some varieties is much like wool in appearance. It is imported chiefly for mixing with wool or for producing special effects.

Kidney cotton is found in Central America and also in the Philippines and other tropical islands of the Pacific, but it is not cultivated in commercial quantities outside of South America. In length of staple it varies from $1\frac{1}{8}$ to $1\frac{7}{16}$ ins., with a mean of $1\frac{1}{4}$ ins.; its mean diameter is about 0.00078 in. Most of the fibers are only partially twisted. The

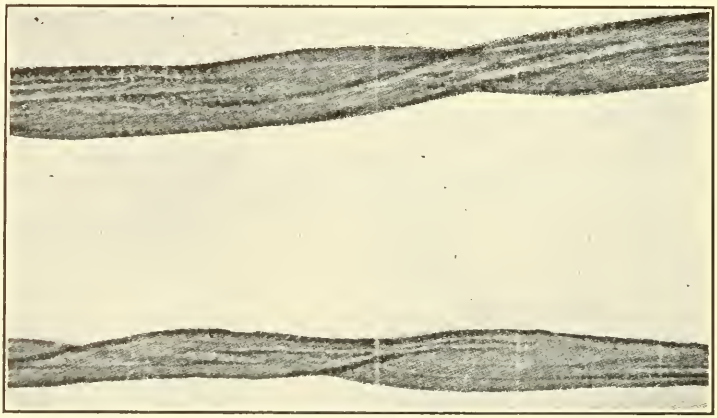


Fig. 181.—American Delta Cotton.

yield of native Peruvian is very high; it is said to average as much as 625 lbs. per acre.

Rough Peruvian cotton is mostly grown in the valleys along the banks of the rivers Chira and Piura. It is a tree cotton with an approximate age of six to seven years. It grows to a height of 8 to 10 ft. and is kept down as much as possible, for convenience on picking the cotton. The tree grows two crops a year, which is rather remarkable when we consider that there is little or no rain in the district; the moisture, however, is derived from the irrigation of the rivers and the heavy dews. The crop of " full rough " cotton is not a large one, the heaviest on record occurring in 1913, when 8,799,216 lbs. were marketed. As already stated, there are two crops a year, one being known as the San Juan crop and the other as the Navidad crop. About two-thirds of the cotton produced comes from the section known as Catacaos. The ginning is done on Eagle or Brown gins. The price is partly regulated by the size of the bales,

which vary from 175 to 360 lbs. in weight. This is due to the fact that the transportation is on the backs of mules. After ginning the cotton is sorted for stains; the first sort is called "segunda," or second; the next "mestizo" or half breed; the third "omarillo" or yellow. There is also a "double omarillo (AA)," the lowest sort of all. Another sort consists of the very roughest type of cotton, deeply stained; this is called in England "foxy red," but in Peru it is known as "pardo" (brown), being of the shade of camel's hair. The production of this grade, however, is very small.

There is also the "moderate rough" Peruvian cotton, which is chiefly known to manufacturers in the United States. This cotton has most of the characteristics of the "fully rough" variety, but as its name implies, does not have to the same degree the wiry harshness of its northern cousin. The sorting of this quality is not done as carefully as with the other cotton, also the crop is constantly diminishing in quantity, giving place to the better stapled "Mitafifi" variety. The crop of the "moderate rough" variety amounts to about 4,500,000 lbs. a year. The Catacaos district raises the very best of the "fully rough" cotton, and it is from this section that the famous FHC and DFC brands come, these marks being originally used by certain firms with established reputations. In the United States it is customary to grade the products of the different districts by name and number, as, for example, "No. 1 Full Rough Catacaos," "No. 1 Full Rough Sullana." The characteristics of "full rough" Peruvian cotton may be given as a staple averaging $1\frac{3}{8}$ ins., a "harsh" feel like wool; the diameter of the fiber is about twice that of Texas cotton, while its color is close to that of scoured wool. It will spin easily to 70's, and the yarn has a good breaking strength. Its price is influenced by that of American cotton, being a few cents per pound above that of strict good middling Texas cotton. The shrinkage, or the amount of foreign substances, is the lowest found in any commercial cotton, owing to the fact that it is a true tree cotton, and consequently the fiber does not become contaminated as easily as is the case with shrub cotton.

Smooth Peruvian cotton has a soft, smooth feel, but the staple is not so strong as the preceding. The length is about the same as the foregoing, as is also the diameter. *Pernambuco* has a slight golden color and feels harsh and wiry. It is a variety of Brazilian cotton. It is rather regular in length of staple, the mean being $1\frac{1}{4}$ ins. The diameter averages 0.00079 in. Under the microscope the twists appear regular and well defined.

Maranhams is a Brazilian cotton very similar to the preceding in microscopic appearance and length and diameter of staple.[1] *Ceara* is also a Brazilian cotton, rather inferior to the others by reason of its considerable

[1] Brazilian cotton from 1781 to 1800 was the chief source of the Lancashire cotton supply; but after that date American cotton quickly took its place.

variation in length of staple. *Maceo* is a similar variety, but somewhat harsher. The variety known as *G. braziliense* is a representative of the so-called "kidney cottons." In these cottons the seeds of each cell are loosely adherent in an oval mass, whereas in the other varieties of cotton the seeds are free from each other. *G. braziliense* is an arborescent plant with very large 5 to 7 divaricate-lobed leaves and very deeply laciniate involucral bracts. The Brazilian cottons appearing in trade under the names Santos, Ceara, Pernambuco, etc., do not seem to belong to

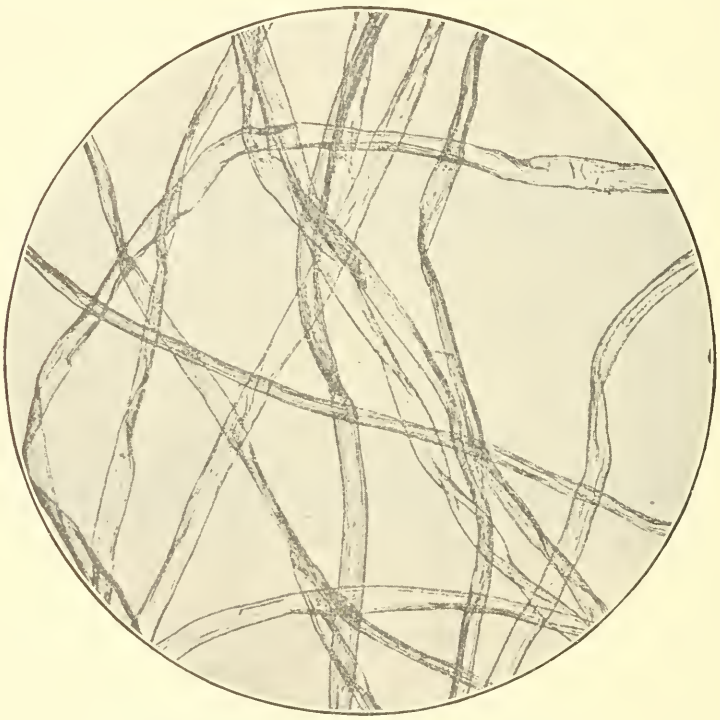


FIG. 182.—Cotton from *G. religiosum*. (Herzog.)

G. braziliense, as they are not kidney cottons; they evidently belong to the *G. barbadense* and *G. herbaceum* species.

West Indian cottons nearly all belong to the *peruvianum* species; they are usually long in staple and harsh and wiry in feel, and only of moderate strength. The length is quite uniform and averages $1\frac{1}{4}$ ins. The diameter varies considerably, but has an average of about 0.00077 in. The twist is short and very uniform, surpassing even Sea-island in this respect.

Owing to the fact that the fiber closely resembles wool in appearance and quality, almost the entire crop of Peruvian cotton is used in the manufacture of merino goods, being mixed in varying proportions with

wool fiber. It finds an extensive use in the manufacture of mixed woolen underwear. When carded its resemblance to wool is very close and its characteristics are quite similar to the animal fiber, having a rough woolly, strong, and crinkly staple. So that when woven in fabrics along with wool, from a casual examination the cotton fiber is not apparent. When mixed with wool it reduces the tendency of the fabric in which it is used to shrink; it also gives a good luster and finish, besides reducing the cost of manufacture. For these reasons it is largely used with wool in the manufacture of underwear and hosiery.

16. Chinese Cotton.—This includes the majority of the Bengal and Chinese cottons of commerce and these are derived mostly from *G. arboreum.* A variety of Chinese cotton known as *Nankin* cotton is classified as *G. religiosum;* it yields a naturally colored fiber, being rather dark yellowish brown. It grows principally in China and Siam. The *Dacca* cotton from which the famous muslins were made is said to be derived from *G. neglectum,* a variation of *G. arboreum.* This species is indigenous to India where it was extensively grown as a field crop. The boll is small in size and contains only a small number of seeds. The fiber is remarkable for its fineness and silkiness, though it has a rather short staple. During the past century, the cultivation and quality of this cotton has seriously declined, though it is still grown in a very restricted area.

17. Grading of Cotton.—The principal factors in the grading of cotton are length of staple, uniformity, strength, color, cleanliness, and flexibility. The first may be determined by the gradual reduction of a tuft of cotton by the hand until individual fibers are drawn from the tuft, so that their length may be ascertained. The uniformity of staple is also important, for if the staple is uneven the cotton is of less value than if it were somewhat shorter but more even. The color of the fiber must also be considered, because this is of importance in maintaining an even shade of yarn. The cleanliness of the fiber affects the amount of waste made in the mill and hence is an item of great importance. The flexibility of the cotton is best ascertained by the feel; flexibility does not necessarily imply lack of strength, but rather includes it, for a weak fiber is more liable to be brittle than flexible. On the other hand, a fiber may also be strong and harsh and yet not flexible, and hence less suitable for fine spinning. The strongest cottons are used for warp yarns as such yarn is required to withstand considerable strain during weaving, a feature which is not required to such an extent by filling yarns. The latter, however, require a soft and flexible fiber. According to Earl and Dean (*U. S. Bureau of Plant Industry*), the present method of grading cotton dates back to about 1800. Until recently, very few growers have had the opportunity of acquiring the knowledge of classifying or grading cotton.

The objects of grading and classifying cotton are to aid (1) in determining the comparative values of the different qualities, and (2) in describing the cotton so as to make buying and selling easier when there are no samples. With the present methods of buying cotton, especially the short-staple varieties ($\frac{3}{4}$ in. to $1\frac{1}{16}$ in.), other things being equal, the grade practically determines the price that is received by the producer. What is known as staple cotton ($1\frac{1}{8}$ in. staple or above) is usually sold on sample. The sample gives each party to the trade a chance to form his own opinion, and is necessary because cotton dealers and spinners have such different ideas about the character and length of staple.

The classification of American mainland cottons is generally done by means of seven full grades, which may also be divided into half and quarter grades, thus giving a scope of 7 full, 13 half, or 25 quarter grades, as circumstances demand. The full grades are: fair, middling fair, good middling, middling, low middling, good ordinary, and ordinary. The half grades are designated by the prefix "strict"; and the quarter grades by the prefixes "barely," meaning the intermediate quality between the half grade and the next full grade above, and "fully" which is between the half grade and the next full grade below. Sea-island cottons are graded as follows: extra fine, fine, medium fine, good medium, medium, common, and ordinary. Egyptian cottons as a rule, are quoted under four or five grades: good, fully good, fair, good fair, and fair. Between the grades good and fully good fair, there is often an intermediate adopted, called extra fully good fair. In the commercial grading of cotton a classification is adopted with reference to the quality of the fiber. The usual grades are as follows:

Fair	Good middling
Strict middling fair	Strict middling
Middling fair	Middling
Strict good middling	Strict low middling
Strict good ordinary	Middling tinged
Good ordinary	Strict low middling tinged
Strict good middling tinged	Low middling tinged
Good middling tinged	Middling stained

The "fair," "middling fair," "middling," etc., are known as full grades, while those intermediate are half grades. The "middling" grade is the one universally employed as a basis for all cotton trading, and the price of cotton is fixed on this standard.

The above list of sixteen grades are those deliverable upon contracts of the New York Cotton Exchange (April, 1908). Prior to January 1, 1908, nine other intermediate grades, known as "quarter grades," were recognised, but these were eliminated on that date, as were also two other grades, "low middling stained" and "strict good ordinary tinged."

On April 1, 1908, "strict low middling stained" was also excluded from the list of deliverable grades in the New York market.

The grade names that are in more or less general use throughout the United States for what is known as American cotton are given below:

Above Middling.		Below Middling.
1. Fair.		8. Strict low middling.
2. Strict middling fair.		9. Low middling.
3. Middling fair.	7. Middling.	10. Strict good ordinary.
4. Strict good middling.		11. Good ordinary.
5. Good middling.		12. Strict ordinary.
6. Strict middling.		13. Ordinary.

The official grades, as prepared at present by the United States Department of Agriculture, include only nine of these—namely, middling fair to good ordinary, inclusive. In an average season this range of grades covers practically all the white cotton grown. The grade names containing the word "Strict" are known in the trade as half grades, and others as full grades.[1]

The grades from fair to good ordinary in the above list are what is known as white cotton. The "tinged" and "stained" grades are cotton showing discoloration. Tinged cotton is cotton that is only moderately discolored; that which is deeply discolored is known as stained cotton. The grade names given in the above list are used in nearly all Southern markets. The terms "tinged" and "stained," however, are used in the South in a general way to indicate cotton of the respective grades which has become more or less discolored, rather than to indicate a distinct style of cotton, as at New York. The range of grades deliverable on contract in New Orleans is about the same as that permitted by the New York contract. The New Orleans contract, however, contains the important provision that no cotton shall be deliverable which is of a lower market value than good ordinary cotton of fair color. The New Orleans contract thus excludes considerable cotton which until recently has been tenderable on contracts at New York. Moreover, the New Orleans

[1] Middling, as the name shows, is the middle or basic grade, and is the grade upon which the market quotations are based. All grades above middling bring a higher price, and all below middling bring a lower price, than that quoted for middling, the amount above or below varying according to the respective differences in use where the cotton is marketed. Many more grade names are used by the trade, in the large spot markets to describe the different classes of colored cottons. The grades of white cotton, however, are the foundation of all these other classes. When the cotton is not white, its nature is indicated by adding the words "off color" or "fair color," "spotted," "tinged," or "stained," as the case may be, to the grade given to the sample. In other words, there may be several classes of the same grade of cotton, namely, middling "off color," middling "tinged," or middling "stained."

classification is generally conceded to be more rigid, grade for grade, than that of New York; so that cotton of a given grade name in the New York classification might not necessarily be given the same grade in New Orleans. The relative values of different grades of cotton and different staples at the same market (New Orleans, April 1, 1913) is given in the following table:[1]

Grade.	Staple in Inches.								
	1	1 1/16	1 1/8	1 3/16	1 1/4	1 5/16	1 3/8	1 7/16	1 1/2
	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.
Middling fair	13 3/8								
Strict good middling	12 7/8	14	16 1/2						
Good middling	12 3/4	13 3/4	16	17	18	19 1/2	21	22	22 1/2
Strict middling	12 9/16	13 1/4	15 1/2	16 1/2	17 1/2	19	20 1/2	21 1/2	22
Middling	12 3/8	12 7/8	15	16	17	18	19	20	20
Strict low middling	12 3/16	12 13/16	14	15	16	17	18	19	19
Low middling	11 7/8	12 5/16	13	14	15	16	17	18	18
Strict good ordinary	11 5/8	12	12 1/2	13	14	15	16	16	16
Good ordinary	11 3/8	11 3/4	12	12 1/2	13 1/2	14	14 1/2	15	15

In the trade, the grades above middling are usually referred to as the "higher grades," and those below as the "lower grades."

An important feature of future business in cotton is that, broadly speaking, cotton delivered on contract consists of the surplus grades or remnants of the more desirable grades. Even-running cotton—that is, cotton of substantially one grade—can ordinarily be sold to spinners at a premium above the price of a mixed assortment of grades; consequently buyers will not pay as much for a mixed assortment of cotton as for even-running cotton. The spot merchant, therefore, endeavors to class out his cotton into even-running lots and to dispose of it in the spot market instead of tendering it on contract, using the contract market to get rid of surplus grades or broken lots, known in the trade as "overs." For these reasons a mixed assortment of grades is often delivered on a single contract.

There are a number of terms employed in the grading and selection of cotton which it might be of interest to explain. A good glossy, full-bodied fiber which has been well ginned and packed will reflect the rays of light very well, and is for this reason called "bloomy." "Blush" is

[1] *Bull.* 591, *U. S. Dept. Agric.*

sometimes employed for the same purpose. "Tinged," "stained," and "spotted" explain themselves, as do also "musty," "sandy," and "leafy." "Musty" cotton is caused by dampness, and the unmistakable musty smell is a sure indication of an excess of moisture. "Sandy" cotton is readily detected by holding a sample up to the light and gently shaking it, when the fine particles will sometimes feel like a miniature cloud; by passing the palm of the hand over the place where the samples have lain on the open paper, sand can always be detected if present in any quantity. "Bant" is a term mostly used in speaking of twist cottons, and denotes strength and all-round general utility; "bony" is sometimes employed to designate the same features. "Soapy" and "waxy" are used to describe the sensations experienced when cotton with these characteristics is passed through the fingers. "Green" cotton is a name given to lots which have been picked before the plant was properly matured; this kind of cotton is seldom met with except at the beginning of the season. It is really unripe and contains a large amount of natural moisture. In "green" cotton the twists have not developed and this cotton is not suitable for good spinning. "Staple" cottons are those intended for twist or warp yarns.

The chief factors in the determination of the commercial grade of cotton are:

(1) Foreign matter including
  (*a*) Leaf.
  (*b*) Dirt and sand.
  (*c*) Motes.
  (*d*) Neps and cut fibers.
  (*e*) Stringy cotton.
  (*f*) Cut seeds.
  (*g*) Unripe fibers.
(2) Color.

Grade and value do not run parallel except for cottons that have the same qualities of staple; that is to say, the cotton merchant must rate the strength, length, pliability, cling, and evenness of the staple as well as the grade. The relative spinning value of cotton must be considered apart from the grade. The chief foreign impurities in cotton are as follows:[1]

[1] A very important factor in determining the grade of a cotton is its freedom from foreign impurities, such as leaf, boll, husk, stalk, seed, and sand. These impurities are present to some extent in all cotton, but the amount depends largely upon the care with which the cotton has been gathered. The greater the amount of any of these impurities, the lower will be the grade. The percent of trash, etc., does not run uniformly, however, in the same grade of different samples of cotton, for the reason that this defect may be offset by some desirable quality in one sample, or increased

Leaf, Dirt, and Sand.—The amount of leaf, dirt, and sand in the sample depends upon the weather. Usually there is very little leaf when the cotton is picked before the vegetation is killed by frost. The dirt and sand may be caused by either wind or rain. Many of these impurities may be taken out at the gins by the use of cleaners. Fifty pounds or more can very often be extracted from one bale of low-grade cotton. If up-to-date machinery could be used for the whole crop, there would be but few bales grading below low middling. If, then, the cotton was sold

by some undesirable quality in another sample. The average percent of impurities in the various grades, assuming other qualities to be uniform, is approximately as follows:

	Percent.
Strict good middling	11.5
Good middling	12
Strict middling	12.5
Middling	13
Strict low middling	13.75
Low middling	14.75
Strict good ordinary	16
Good ordinary	17.50
Ordinary	19

The difference in the value of these grades is usually greater to the spinner than these figures would indicate, since the staple of the lower grades is very often weaker and of a darker color than the higher grades.

To show where the impurities are taken out in the manufacturing process, the results of an experiment made with a good middling cotton are given as follows:

	Percent.
Opener and breaker	2.32
Intermediate lapper	1.69
Finisher lapper	1.44
Picker room total	5.45
Stripping on card	2.60
Licker-in on card	0.50
Flying on card	0.22
Toppings on card	2.00
Total on card	5.32
Drawing (3 processes)	0.33
Slubber frame	0.08
Intermediate frame	0.06
Roving frame	0.06
Total on frames	0.53

The total percentage for picker and card-room is 11.29 percent.

on grade, the increase in price would offset the loss in weight, and at the same time the cost for ginning would be reduced. Much of the leaf, dirt, sand, and hulls may be removed by the use of "huller" gins. All types of gins turn out cleaner and better samples if the cotton is thoroughly dry when ginned.

Motes are immature seeds or ends of seeds that are pulled off in the ginning. Immature seeds are found more or less in all cotton, the number depending upon the variety and the weather conditions during its growth and maturity. They go out as waste in the manufacturing processes, and their presence lowers the grade.

Neps and *Cut Fibers* may be caused by feeding the gin too fast, by the gin being in bad order, by the presence of unripe fiber, or by dampness in the cotton when ginned. Neps look like small dots. They may best be seen when a thin layer of the cotton fibers is held toward the light. The cut fibers show in bunches and V-shaped kinks, and give the sample a rough appearance. It is difficult to judge the grade or value of gin-cut cotton; in order to be on the safe side, the buyer often penalises such cotton from 1 to 3 cents per pound.

Stringy Cotton is defective cotton produced by ginning wet or unripe seed cotton, or sometimes by a wrong adjustment of the brushes that take the lint away from the gin-saws. The fibers in these strings do not separate very easily, while many of them are knocked out in the cleaning processes at the mill, and go into the waste.

Cut Seeds are caused by fast ginning with a hard roll and by broken or bent gin-saw teeth that strike the grate-bars. Cut seeds have their effect upon the eye and touch in grading, and should be avoided by the ginner.

Unripe Fibers have a glossy appearance, and are usually matted together. Bolls of cotton that are picked before they are well opened, and also the top bolls that are forced open by the action of frost, usually contain unripe fibers. These fibers are very weak, and they lower the grade, as does dirt or bad fiber of any kind.

Requirements for Satisfactory Ginning.—Cotton should be dry when ginned, and the saws, brushes, and other parts of the gin should be in good condition if a smooth sample is to be obtained. Cleaners used in connection with the ginning of low-grade cotton will improve the sample from one to two grades.

Color.—The weather and the soil are the factors that influence the color of cotton. The early pickings, when not exposed to the rain, usually have a bright, creamy color, and if picked with ordinary care should grade good middling or better. If left in the field too long, however, the luster is lost and the color of the cotton changed to a "dead" or bluish white that may reduce the grade to good middling "off color," or perhaps middling or below, depending upon the quantity of trash and dirt. A rain may

change the same cotton to middling "tinged" or middling "stained," according to the kind of soil and the quantity of rain. Weather-tinged and weather-stained cottons are often of a bluish color, and when not grown on sandy land generally contain mud spots. The action of frost on the late bolls before they open also causes spots, tinges, or stains, depending upon the amount of colored cotton that is mixed with the white. This "frost" cotton has a yellowish or buff color, and is usually weaker than other tinged cotton, owing to the bolls being forced open before the fiber is fully developed.

Cotton picked while wet with dew or soon after rain will contain an excess of moisture. This may cause mildew, and thus give the cotton a bluish cast. A bale of cotton left exposed to the weather in the gin-yard very often has a mildewed outer surface or plate, and a sample drawn from near the surface of such a bale may not afford a fair representation of its color.

The United States official cotton grades, as well as other grade standards, require that cotton grading strict good middling or above should be of a bright creamy or white color, and free from any discoloration. A definite or fixed color is not so absolutely required in the grades below strict good middling. For example, a middling may be creamy or dead white, and the same sample might grade below or above middling, according as it contained more or less impurities. In the grades below strict low middling, however, the creamy color or bloom is lost, since climatic and soil conditions that lower the grade to this extent also affect the color, giving a dead white, a gray, or a dingy or reddish cast to the lower grades, although they pass commercially as white cotton.

The above variations in color can best be seen when the cotton is placed in a north light. If out of doors, the examiner's back should be turned toward the sun, so that his line of vision will be more or less parallel to the rays of light. The best light for grading may be had on a clear day between the hours of 9 A.M. and 3 P.M. It is sometimes hard to judge the color of cotton on a day that is cloudy or partly cloudy, because of reflected light. This difficulty is frequently experienced along a coast where there are numerous clouds. The reflection may be more troublesome when grading near large bodies of water.

Sample for Grading.—In sampling a bale of cotton for grading, about 3 ozs. should be drawn from each side of the bale from a sufficient depth to be fairly representative. When the samples are drawn from a bale of compressed cotton they should be allowed to lie for a day before grading, so that the matted condition and deadened color may disappear. This should be done for the reason that many bales have a thin plate on one side that is of a higher or lower grade than the rest, usually caused by a

"roll" left in the "breast" of the gin from cotton of a different lot previously ginned.

Tests have been made to show the relative values of the different grades of cotton in terms of the strengths of the spun yarns. The results were as follows:

	Good Middling.	Middling.	Low Middling.	Good Ordinary.
Average breaking strength, lbs...	68.4	71.81	65.4	63.1
Average weight 60 yards, grains..	36.03	38.2	36.9	36.0
Average number.....	13.88	13.08	13.55	13.89
Strength per grain.....	1.89	1.88	1.77	1.75

The U. S. Department of Agriculture has made a study of the waste produced and the character of the yarn made from different grades of cotton.

The following table gives the percentage of waste (visible and invisible) resulting from the manufacture into 22's warp yarn of the five grades of 1-in. upland cotton studied, also the breaking strength (in pounds per skein) of both the unbleached and bleached yarn produced from each grade:

Grade.	Waste, Percent.	Breaking Strength.	
		Unbleached Yarn.	Bleached Yarn.
Middling fair.....	7.43	69.5	66.7
Good middling.....	8.49	63.2	61.5
Middling.....	10.38	60.5	58.3
Low middling.....	12.39	61.4	63.4
Good ordinary.....	16.47	56.4	60.9

A good knowledge of the amount of waste given by different qualities of cotton is an important point for the consideration of the spinner in the valuation of a sample of cotton.

18. Statistical.—The following tables, indicating the extent of the cotton manufacturing industry in the United States for the year 1919, have been taken from the U. S. Census Reports:

ANALYSIS OF COTTON PRODUCTION BY QUANTITY AND VALUE

Article.	Total Square Yards.		Total Value.		Value per Square Yard, Cents.	
	1914.	1919.	1914.	1919.	1914.	1919.
Woven goods over 12 ins. width.	6,813,540,681	6,317,397,984	489,985,277	1,489,610,779	7.2	23.8
Unbleached and bleached sheetings, shirtings and muslins	3,852,471,903	3,194,100,981	196,520,984	477,407,901	5.1	15.0
Ducks	251,367,711	336,500,457	49,179,212	327,082,551	19.5	70.0
Ginghams	489,661,133	368,307,601	36,706,542	85,070,745	7.5	23.1
Drills	289,969,885	314,822,109	21,256,698	73,253,640	7.4	23.0
Twills and sateens	392,108,735	424,478,033	32,891,854	101,056,691	8.4	23.8
Ticks, denims	229,330,389	220,381,180	24,947,983	70,080,557	10.9	31.8
Cotton flannel	263,862,227	268,067,853	24,352,020	60,152,426	9.2	22.2
Velvets, velveteens, corduroys and plushes	29,128,703	40,183,780	8,540,143	36,673,551	29.3	91.3
Toweling and Terry weaves	75,798,907	75,165,515	9,805,232	31,230,370	12.9	41.6
Tapestries	10,137,710	21,705,586	5,411,592	17,295,608	53.2	79.6
Pillow tubing	15,212,622	12,112,573	1,483,847	2,555,543	9.7	21.0
Mosquito netting and tarlatan	99,981,783	34,425,307	2,820,524	3,273,376	2.86	9.45
Bags and bagging	129,357,002	82,433,300	9,705,616	13,139,820	7.5	16.3
Other woven goods over 12 ins. in width	687,151,971	924,713,709	66,363,030	281,338,000		
Lace and lace curtains	.....	.....	12,521,053	28,258,489		
	Lineal Yards.	Lineal Yards.				
Tape and webbing	1,026,231,549	1,065,551,328				
	Pounds.	Pounds.				
Twine	13,284,875	11,860,195	2,792,125	5,935,245		
Cordage and rope	5,515,658	6,815,848	891,223	2,857,275		
Thread	26,507,023	26,441,943	22,917,099	55,009,176		
Yarns for sale	497,986,999	618,201,812	127,363,952	453,764,883		
Cotton waste for sale	317,360,019	315,314,228	14,421,929	36,357,674		

COTTON USED IN COTTON MANUFACTURING

Kind.	1919.	
	Bales.	Pounds.
Total	5,529,422	2,731,404,436
Cotton (raw):		
Domestic	5,329,973	2,612,851,431
Sea-Island	52,154	20,804,901
American Egyptian	40,726	20,695,568
Other long staple ($1\frac{1}{8}$ ins. and over)	961,450	485,010,838
Short staple (under $1\frac{1}{8}$ ins.)	4,275,643	2,086,340,124
Foreign	199,449	118,553,005
Egyptian	128,959	88,710,604
Other	70,490	29,842,401

The cotton industry of the United States shows considerable shifting toward the base of supply; in 1880 there were in the cotton-producing states of the South only 561,000 spindles, whereas in 1922 this had grown to 15,000,000 spindles, or 43.21 percent of all the cotton spindles in the United States.

DISTRIBUTION OF WORLD'S COTTON SPINDLES—FOR YEAR 1920

Country.	Number of Spindles.	Spindles at Work.	Bales of Cotton Used.
Great Britain	58,692,410	50,045,902	3,185,314
France	9,400,000	5,658,630	629,799
Germany	9,400,000	5,230,996	484,911
Italy	4,514,800	3,932,893	670,702
Czechoslovakia	3,584,420	1,603,857	97,877
Spain	1,800,000	1,800,000	390,000
Belgium	1,572,500	1,467,452	234,906
Switzerland	1,536,074	1,380,546	79,514
Poland	1,400,000	126,846	8,184
Sweden	670,350	403,399	70,667
Holland	597,492	593,942	107,975
Portugal	482,000	482,000	67,491
Finland	239,828	239,828	26,257
Denmark	116,644	92,404	23,516
Norway	72,724	62,340	10,269
India	6,689,680	5,318,603	1,695,365
Japan	3,690,090	3,155,271	2,083,433
China	1,600,000	1,280,036	690,398
United States of America	35,872,000	35,499,000	6,425,344
Canada	1,200,000	681,012	118,446
Mexico	720,000	253,424	44,321
Brazil	1,600,000	303,068	75,552
Sundries	250,000	46,140	16,700
Total	145,701,462	119,657,589	17,236,941

THE WORLD'S COTTON SPINNING SPINDLES

Locality.	1919 (in Millions).	1922 (in Millions).
Europe	96.37	99.46
Asia	8.88	13.42
America	31.33	40.19
Sundries	0.25	0.25
Totals	136.83	153.32

The following diagram furnishes some interesting statistics concerning the commercial facts relative to cotton:

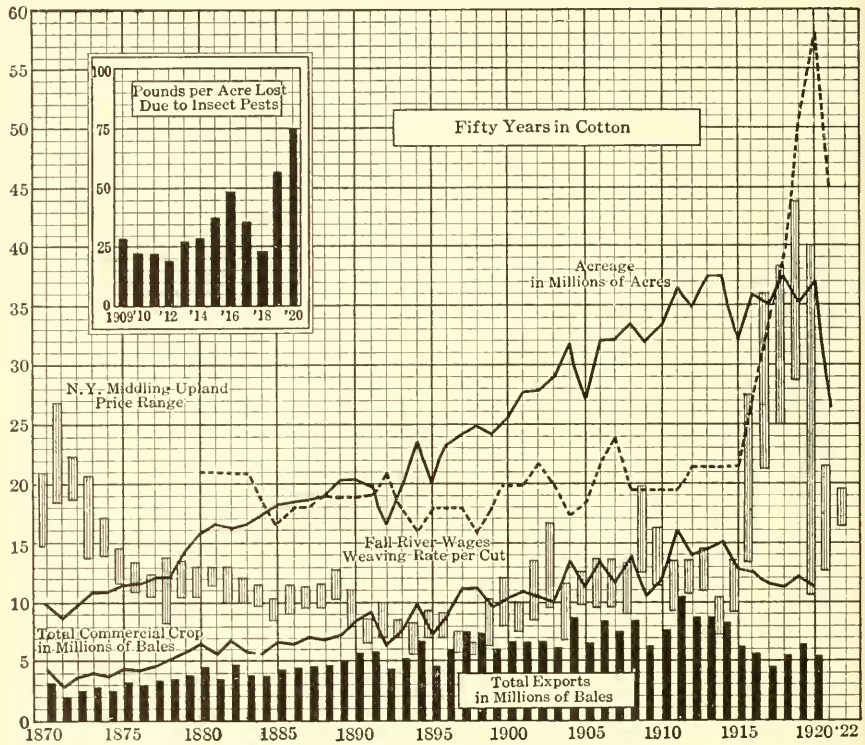


FIG. 183.—Analytical Study of Cotton Production, Wages, Prices and Exports over Fifty Years. (*Magazine of Wall Street.*)

The following are interesting statistics of the cotton industry (1909):

	Pounds.
World production of cotton	8,505,191,000
United States produced	5,157,691,000
British India produced	1,801,000,000
Egypt produced	455,520,000
Russia produced	360,000,000
China produced	300,000,000
Brazil produced	180,000,000
Turkey produced	16,000,000
Value of crop in United States	$700,000,000
Capital engaged in manufacturing	$821,109,000
Value of products	$629,699,000
Number of establishments	1,322
Persons employed	387,252

CHAPTER XIV

THE PHYSICAL STRUCTURE AND PROPERTIES OF COTTON

1. Physical Structure.—Physically the individual cotton fiber consists of a single long tubular cell, with one end attached directly to the surface of the seed. Its length is about 1200 to 1500 times its breadth. The outer end of the fiber is pointed and closed; the end originally attached to the seed is generally broken off irregularly. While growing the fiber is round and cylindrical, having a central canal running through it; but, after the enclosing pod has burst, the cells collapse and form a flat ribbonlike fiber, which shows somewhat thickened edges under the microscope. The juices in the inner tube, on the ripening of the fiber, are drawn back into the plant, or dry up on exposure to light and air, and in so doing cause the fiber to become twisted into the form of an irregular spiral or screwlike band, by reason of the unequal collapse and contraction of the cell-wall.

A study of the growth of the cotton fiber has been made by W. L. Balls (*Proc. Roy. Soc.*, 1919, p. 542); he adopted the method of hydration of cellulose according to Cross and Bevan's partial xanthation process, and obtained a swelling of the fibers which on microscopic examination exhibits well-defined zones corresponding to rings of growth during the day and night, the latter being the active period. It was found that up to the twenty-sixth day there is very little evidence of structure, but from then on to the fiftieth day the development of well-defined growth rings may be detected, together with the formation of pits in the cell-wall and a tendency to produce the well-known twist in the fiber.

The number of twists in the cotton fiber in the raw state is said to be from 150 to 400 per inch. Bowman gives the following table as an approximate estimate of the mean number of twists per inch in various classes of cotton:

Sea-island	300
Egyptian	228
Brazilian	210
American peeler	192
Indian (Surat)	150

2. Unripe or Dead Fibers.—Fibers that have not ripened differ somewhat in these characteristics, being straight and having the inner canal

more or less filled, in consequence of which they do not spin well and are difficult to dye, showing up as white specks in the finished goods; this is known as **dead cotton.** The presence of "dead" or unripe cotton is very objectionable, as the fiber is weak and brittle, and consequently reduces the strength and durability of the yarn into which it may go. There is a considerable amount of unripe or partly ripened bolls always to be found in cotton fields, and the fibers from these consist almost exclusively of "dead cotton" (Fig. 185). The proper utilisation of such cotton is a serious question, for the fiber is too weak to be used for spinning, and the cost of gathering and ginning makes the fiber too expensive for most other purposes, such as for absorbent cotton, cotton batting, or material for guncotton.

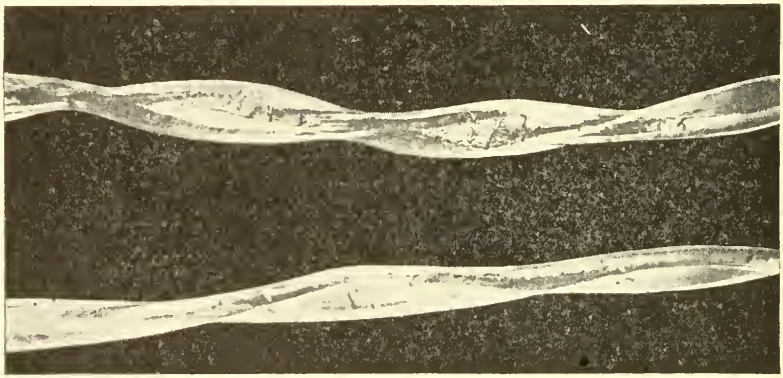


FIG. 184.—Sea-island Cotton under Polarised Light. (×360.) (Herzog.)

According to H. Kuhn, a greater proportion of dead fibers occurs in the coarser varieties of cotton than in the finer, and this is accounted for by the fact that such fibers draw up more juice from the seed, which thus becomes impoverished before the maturity of all the adhering fibers. Dead cotton is far more common in Indian cottons than in Sea-island or Egyptian. Haller states, that unripe cotton fibers differ from the matured fibers in their chemical behavior. A potassium iodide solution of iodine gives a dark yellowish brown color with the ripe fibers while the dead fibers remain a light yellow. On treatment with a zinc chloride solution of iodine dead cotton gives a blue coloration more rapidly than the normal fiber. The dead fibers also show a different reactivity toward many dyestuffs.

Haller[1] gives the following description of the properties of unripe cotton. Under the microscope the lumen is seen to contain a considerable quantity of matter, and the fibers do not appear so twisted as the ripe

[1] *Chem. Zeit.*, 1908, p. 838.

fibers. When treated with an ammoniacal solution of copper oxide, the fibers of dead cotton swell up but do not dissolve. When a mixture of ripe and unripe fibers is treated with a solution of chlor-iodide of zinc, the unripe fibers very quickly develop a blue color, which appears much more slowly with the ripe fibers. A solution of iodine in potassium iodide colors the ripe fibers a dark yellowish brown, whereas the unripe fibers acquire only a light yellow color. When treated with an 18 percent solution of caustic soda, the unripe fiber retains what twist it has, and only becomes lighter and more transparent. The ripe and unripe fibers also exhibit marked differences toward polarised light. If a mixture of the two classes of fibers is boiled in caustic soda solution (2° Bé.), and then soured, washed, and dyed with indigo, the ripe fibers take up the dye-stuff readily, but the unripe fibers are dyed to only a very limited extent. The reverse, however, is the case when dyeing with the substantive dyes, the unripe fibers acquiring a deeper color. When dyed with basic colors on a tannin-antimony mordant, the unripe fiber is only dyed on the exterior.[1]

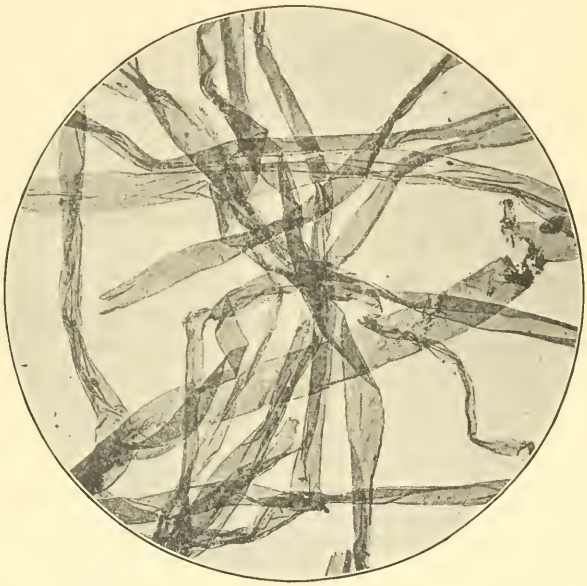


FIG. 185.—Unripe or Dead Cotton Fibers. (Herzog.)

3. Inner Canal or Lumen of Fiber.—The presence of an inner canal in the cotton fiber no doubt adds to its absorptive power for liquids, and

[1] Clegg and Harland (*Jour. Text. Inst.*, 1923, p. 125) have published the results of an investigation on the influence of "neps" consisting of dead cotton hairs on the dyeing of fabrics. It is stated here that a distinction must be made between "unripe" fibers and "dead" fibers. It is the latter that are to be observed in the form of little balls or tangled clumps occurring more or less on the surface of the cloth and these little masses of fiber resist the action of the dye, or at least show up as much lighter in color than the surrounding normal fibers. The undyed effect is said to be due really to the fact that the dead fibers are so thin in section that although really dyed like the rest of the cotton, they appear almost undyed by contrast in the same manner that a thin plate cut from a thick piece of colored glass will appear almost colorless. In other words, the undyed appearance is an optical effect and is not due to the fiber resisting the action of the dye.

its capillary action allows cotton to retain salts, dyestuffs, etc., with considerable power; but too much importance in this respect must not be attributed to the canal, for when cotton is mercerised the canal is almost entirely obliterated by the walls being squeezed together (Fig. 186), and yet mercerised cotton is much more absorptive of dyes, etc., than ordinary cotton. The capillarity of the cotton fiber is no doubt principally due to the existence of minute pores which run from the surface inward. The crystallisation of salts in these pores and in the central canal may lead to the rupturing of the fiber, as, for instance, when filter-paper is made by disintegrating cotton fibers by saturating with water and then freezing.

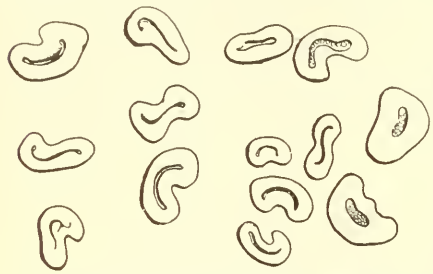


FIG. 186.—Cross-sections of Mercerised Cotton Fibers Showing the Appearance of the Inner Canal.

4. Dimensions of Cotton Fibers.—The following table of the length and diameter of different varieties of cotton fibers has been collated as a mean of several observers:

Name of Cotton.	Length, Mm.	Diameter, Microns.	Name of Cotton.	Length, Mm.	Diameter, Microns.
Sea-Island	41.9	9.65	*West Indian*	32.3	19.6
Edisto	46.6	....	*American*	....	20.9
Wodomalam	39.0	....	Orleans	27.0	19.2
John Isle	39.3	....	Upland	29.5	19.4
Florida	45.7	16.18	Texas	24.3	16.6
Fitschi	48.7	16.7	Mobile	25.0	19.4
Tahiti	42.9	16.3	Georgia	25.4	10.3
Peruvian	38.9	15.3	Mississippi	24.2	13.4
Egyptian	32.1	16.7	Louisiana	25.0	
Gallini	37.2	17.1	Tennessee	25.1	15.0
Brown	34.4	18.7	*African*	27.6	20.8
White	31.8	19.5	*Indian*	....	19.3
Smyrna	28.5	22.8	Hingunghat	28.3	20.0
Brazilian	....	18.8	Dhollerah	28.2	21.5
Maranham	28.8	20.4	Broach	20.9	21.8
Pernambuco	35.2	20.0	Tinnevelly	23.0	21.0
Surinam	30.2	....	Dharwar	23.6	21.0
Paraiba	29.7	....	Oomrawuttee	24.1	21.5
Ceara	28.1	20.0	Comptah	23.8	21.5
Maceo	29.3	....	Madras	21.8	21.8
Peruvian rough	29.9	21.5	Scinde	20.4	21.3
Smooth	30.0	21.5	Bengal	25.7	23.7
Agerian	37.5	....	*Chinese*	21.4	24.1

The cotton fiber is rather even in its diameter for the greater part of its length, though it gradually tapers to a point at its outgrowing end. The point of the fibers may occur in a variety of forms: cone-shaped, spatula-shaped, rounded off, club-shaped, etc. Generally it is very thick walled. Many varieties of cotton exhibit a marked "tail" toward the apex, particularly the finer and longer staples. These tails have no convolutions, and practically no central canal or lumen, the space being almost filled by the secondary thickening. The apex itself may exhibit various shapes, acutely conical, blunt ended, spatulate, or club-shaped,[1] though little is known as to its exact structure. These tails are said by some manufacturers to break off in the various processes preparatory to spinning, but confirmation of this opinion is required. The different varieties of cotton show considerable variation, both in length and diameter of fiber; in Sea-island cotton the length is nearly 2 ins., while in Indian varieties it is often less than 1 in. The diameter varies from 0.00046 to 0.001 in.; the longest fibers having the least diameter.

Bulletin No. 33 (U. S. Dept. Agric.) gives the following table compiled from numerous measurements taken during a period of years, showing the maximum, minimum, and average length of fiber for some of the most important varieties of cotton, as well as the average diameter of the same:

Variety.	Length in Inches.			Diameter, Inches.
	Maximum.	Minimum.	Average.	
Sea-island	1.80	1.41	1.61	0.000640
New Orleans	1.16	0.88	1.02	0.000775
Texas	1.12	0.87	1.00	0.000763
Upland	1.06	0.81	0.93	0.000763
Egyptian	1.52	1.30	1.41	0.000655
Brazilian	1.31	1.03	1.17	0.000790
Indian varieties:				
Native	1.02	0.77	0.89	0.000844
American seed	1.21	0.95	1.08	0.000825
Sea-island seed	1.65	1.36	1.50	0.000730

From these measurements it will be observed that, as a rule, the longer the fiber the less is its diameter. The extreme variations in the above measurements of length is from 0.25 to 0.30 in. In proportion to the size of the fiber, the variation in diameter is much greater than that for the length.

[1] Höhnel, *Die Mikroskopie der Technisch Verwendeten Faserstoffe*, 1905, p. 30.

Deschamps [1] classifies commercial cottons into: (*a*) fine cotton with fibers up to 20 microns diameter; (*b*) ordinary cotton with fibers from 20 microns to 23 microns; (*c*) coarse cotton with fibers of 23 microns and over.

5. Measurement of Cotton Staple.—There are two general characteristics of cotton samples considered in the selection by the spinner, the grade, and the staple. The factors that principally influence the grader are, first: leaf, dirt, sand, or other foreign substance; second, color; and third, the handling or ginning. Staple refers primarily to the length of the fibers, and indicates that characteristic of a percentage of the fibers contained in a given bulk. Staple cotton is generally referred to by the trade as cotton that is $1\frac{3}{16}$ ins. or better in length. Length, strength, luster, "cling," and other spinning qualities are recognised only in a general way in grade standards, but are especially characterised in stapling. The staple of cotton is in fact an expression of its suitability for certain purposes, judged from a generally recognised appreciation of varying factors. The perspicacity of the judge is a factor of the most varying functions, and this is again subjected to fluctuations of temperament and practical experience of the working values of the characteristics of the fibers he may be selecting. This introduces a personal element difficult to estimate, and it is not often that the buyer can or does test his own personal knowledge by actual results in the spinning practice. The cotton spinner's estimate of cotton value is based on average of the varying factors, chiefly upon hair length. This factor is emphasised, perhaps, for two reasons: the length of the fiber is to some extent indicative of other characteristics, and it is the easiest recognised. On this particular point one will find the nearest approach to agreement in the judgment of experts.

There is one general method of estimating the length of the fibers, that is, to select a bunch of fibers, straighten out or parallelise the individual hairs between the finger and thumb and ascertain the length of the tuft so formed. This method takes cognisance only of a certain percentage of the hairs contained in the selected bunch and does not indicate the relative percentage of short hairs contained in the body of the tuft or those fibers removed during the operation of smoothing out the fibers. Some general idea of the uniformity of the fibers may be obtained by pulling a fairly large tuft of cotton apart by both hands; the appearance of the edges of both tufts indicates the regularity of length of fiber, but it is vague. A "hard" edge, that is, one in which the ends of cotton appear to be all the same length, is supposed to indicate a regular staple. This method may be applied with varying degrees of accuracy; the master carder will test the staple from a few hairs drawn from the already straightened "preparation" and placed on his sleeve, while the expert cotton buyer

[1] *Le Coton*, p. 165.

will carefully prepare the tuft by a dozen or more drawings from the tuft and place each separately on a block covered with black velvet or plush with more exact measurements and observation of other characteristics. In the former case, most of the natural short hairs may have been removed in process, while some long ones may have been broken in the cleaning and carding. In the latter, as many as possible of the shorter hairs will be retained and will be exhibited for estimation. An astute buyer will by this method estimate within a very small margin the amount of waste that should occur in the spinning process, always assuming that the machinery is technically correct.

The former method may be considered a commercial or technical one; a scientific procedure is one introduced by Dr. N. A. Cobb, a cotton expert, formerly chief of the Department of Agriculture at Washington, D. C. In this system, fibers are taken from the mass of ginned cotton (or from the seed) and distributed thinly between two glass slides; the image of the fibers is projected on to a screen, by means of a lens and a strong light. The fibers are exhibited highly magnified and in a natural condition, and several characteristics are rendered visible: the curl of the hair, the convolutions, etc. The length of the hair is measured by a map measurer run along each fiber. Dr. Cobb does not claim for this any commercial utility, but it is obviously a valuable method in research work. Its limitations are the small number of hairs that can be operated on at one time, and the tedious use of the map measurer.

It has been mentioned that in preparing the cotton tuft for the commercial estimate of length, many short fibers are discarded, probably not the extremes of, say, $\frac{1}{4}$ in., but mostly those of a length more nearly approaching the average staple. Even if the former were all removed they would affect the relative percentages very little. To illustrate this effect a collection of fibers extracted from a bale of $1\frac{3}{16}$ in. American cotton and measured by Dr. Cobb's method shows:

				Percent.
Fibers of	$\frac{1}{4}$ in.	to	$\frac{3}{8}$ in.	4
"	$\frac{1}{2}$ "	"	$\frac{5}{8}$ "	11
"	$\frac{3}{4}$ "	"	$\frac{7}{8}$ "	16
"	1 "	"	$1\frac{1}{8}$ "	18
"	$1\frac{1}{4}$ "	"	$1\frac{3}{8}$ "	27
"	$1\frac{1}{2}$ "	"	$1\frac{5}{8}$ "	16
"	$1\frac{3}{4}$ "	"	2 ins.	8

If, however, the tuft of cotton were reduced in smoothing out till the lengths below 1 in. were eliminated, the resulting fibers would show a different and evidently incorrect appearance, for the resultant measurements would be:

	Percent.
Fibers of 1 in. to $1\frac{1}{8}$ in.	26
" $1\frac{1}{8}$ " $1\frac{1}{4}$ "	40
" $1\frac{1}{2}$ " $1\frac{5}{8}$ "	23
" $1\frac{3}{4}$ " 2 ins.	11

which is quite a different proposition from a spinner's point of view. It is quite within the range of probabilities that a proportion of the longer fibers would also be discarded in the smoothing process.

Commercial stapling may be considered as a sorting of the fibers in length, with the elimination of unsuitable hairs, and in this extraction lies its inherent weakness. Every machine necessary in the preparation and spinning of cotton may also reasonably be considered a sorter, since it will reject certain lengths of fiber, although replacing them by similar ones made on the premises. The practical spinner knows or can easily ascertain in a varying degree whether his estimate of the fiber in the " raw " is confirmed or otherwise by the resultant sliver or yarn, but there are many variants to be considered, including his temperament at the time of selecting, and the effect of the machinery on that particular type of cotton.

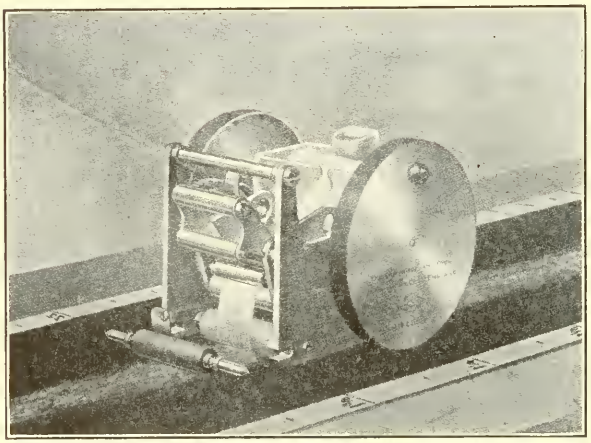


FIG. 187.—Sledge Pattern Sorter. Front view partially dismantled.

To remove as effectively as possible the results of the personal equation, Dr. Lawrence Balls has invented a mechanism which will sort a small amount of cotton into its different component parts in order of their length. This novel device is appropriately named the " Sledge Pattern Sorter," and is elaborately described in a handbook issued by the Fine Cotton Spinners and Doublers' Association Experimental Department. While this " sorting " apparatus is based on the drafting function of a series of rollers, it differs from the ones in use in the spinning technique, in so far as the latter have an equalising effect on the various fiber lengths as they occur (a mixing of the different hairs), and the purpose of the " sorter " is a fractionating one, separating the shorter from the longer and retaining the whole collection. Its inception arose from a need of a

method which would measure, with reasonable and definite accuracy, the length of every hair in a large number of hairs (these being themselves a true sample), would work without subjective error, be reasonably fool-proof, and yet complete the test in a few minutes. The sorter, we are told, fulfills these requirements.

The instrument consists of a small frame, partly sliding (as a sledge), partly rolling on two rear wheels, along a 6-ft. strip of black plush. The plush serves to comb off and to retain the sorted hairs, while the carriage contains all the operating mechanism; in addition it carries the feed box into which the prepared sliver of cotton is placed and presented to the feed rollers. The cotton to be tested is prepared by carding, to disentangle the hairs, and by drawing, smoothing, or parallelising them into a sliver, to render it in a condition to be presented to the feed rollers and to free each fiber to the fractionating action of the intermediary and delivery rollers. These operations may be performed by hand, care being taken that in each process all the fibers are retained. The amount of cotton to be operated on in the sorter must not exceed 7 grains on a length of 8 ins.

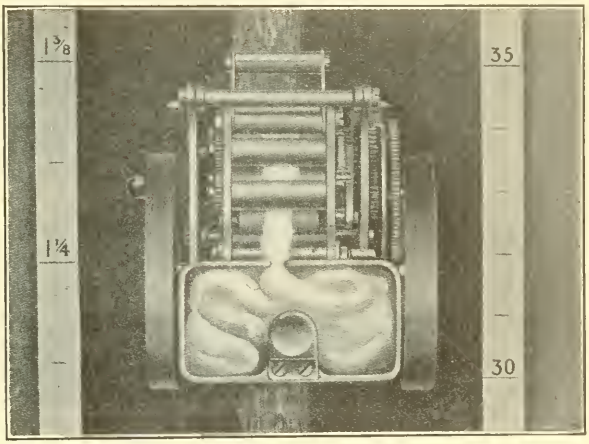


FIG. 188.—Sledge Pattern Sorter. Plan view, showing deposit of fibers on plush.

There is deposited on the plush a tuft of cotton $2\frac{1}{2}$ ins. in length extended over approximately 72 ins. The short fibers are the first to escape on the lower side of the delivery rollers, the long ones will be the last, and the intermediate lengths will appear on the plush at various points between, and each one will appear on the plush separate and distinct from zero to the termination of the traverse. To indicate these lengths a calibrated tape is stretched from end to end along the plush, and is divided into distances representing $\frac{1}{16}$ in. or 1 mm. These distances are proportional to the draft of $2\frac{1}{2}$ to 72.

While this apparatus doubtless has great value from an experimental point of view, it is not so useful in a practical way in the cotton mill for determining the staple of various samples of cotton from the bale before purchase, as the apparatus requires the

use of a prepared sliver which cannot be obtained with a small sample off-hand.

Another form of instrument for measuring the length of cotton staples is the Baer apparatus (Fig. 189). It consists of a still frame with vertical slides, in which are placed nine fine combs of steel pins on brass bars. These combs can be held in position at the top of the slides by means of two steel pins. Over the nine combs, and fitted to fall between the back four, are three other combs. With this apparatus is also supplied a pair of wide-jawed tweezers for taking up the fibers, a small wooden rake for putting the fibers in the wire combs, and a needle for equalising and parallelising the fibers when these are placed on the velvet-covered plate.

The sample of cotton which should be stretched and doubled with the fingers and then slightly twisted so that it resembles a strip of 1's count

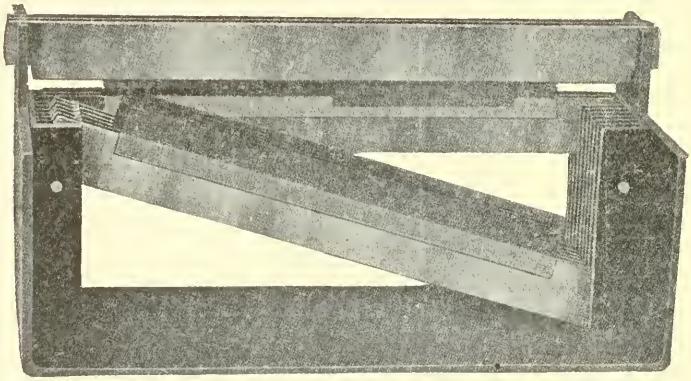


Fig. 189.—Baer Apparatus for Measuring Cotton Staples.

about $2\frac{1}{4}$ ins. long—is placed on the left side of the apparatus across the bottom combs. The point of this strip must stick out about 1 in. behind the apparatus. The apparatus is then turned around so that its back is toward the operator, who seizes the projecting point of the sample with the tweezers and draws out the fibers. To clean them he draws the fibers several times through the last comb and then lays them to one side on the bottom combs, where they can afterward be caught by the fine upper combs. In doing this the tweezers should be in contact with the last comb. The operation is repeated, taking only the extremities, until all the fibers have been selected, cleaned, and laid out on the combs. The fibers are then thrust into the combs with the small wooden rake. The three upper combs are now placed in position, the teeth passing through the prepared strip. Again the apparatus is turned around so that the front of the apparatus is toward the operator. A chalk line is drawn on a velvet-covered plate to form a base line. If any fibers project beyond the first

comb the longest of these is seized by the tweezers, drawn out, and placed on the left of the plate. This operation continues, combs being dropped out of the way as the longer fibers are removed. Finally the upper combs are successively removed with the lower ones until the last lot of fibers are placed upon the velvet.

The object of the apparatus is to assist in making a selection of fibers by length from a sample, with the object of arranging them so that an accurate diagram may be produced. This diagram is derived by spreading the fibers, as described below, on an aluminium plate covered with black velvet. But over this diagram of fibers may be placed a sheet of glass graduated in inches and fractions, and accurate measurements and percentages can thus be derived. Still another method is to spread over the diagram a sheet of transparent squared paper upon which the outline of the diagram can be traced and a permanent record of the sample taken.

6. Staple of Commercial Cottons.—Hannan gives the following varieties and qualities of cotton to be met with in commerce:

Types.	Variety.	Length, Inches.	Diameter, Inch.	Counts.	Use.	Properties.
Sea-island..	Edisto.....	2.20	0.00063	300–400	Warp or weft	Long, fine silky, and of uniform diameter
	Florida.....	1.85	0.00063	150–300	Do.	Shorter, but similar to above
	Fiji.....	1.75	0.00063	100–250	Do.	Less uniform in length, but silky and cohesive
	Tahiti.....	1.80	0.00063	100–250	Do.	Good, fine, and glossy staple
Egyptian...	Brown.....	1.50	0.00070	120–down	Do.	Long, strong, highly endochromatic
	Gallini.....	1.60	0.00066	250–down	Warp	High-class staple of good strength
	Menouffieh...	1.50	0.00066	200–down	Weft	Of good staple and luster
	Mitafifi.....	1.25	0.00066	100	Warp or weft	Fairly good staple
	White.....	1.00	0.00078	70	Do.	Pearly white, good long staple
Peruvian...	Rough.....	1.25	0.00078	50–70	Warp	Strong, woolly, and harsh staple
	Smooth.....	1.00	0.00078	50–70	Weft	Less woolly, and softer staple

Types.	Variety.	Length, Inches.	Diameter, Inch.	Counts.	Use.	Properties.
Peruvian...	Red.....	1.25	0.00078	40–50	Warp	Color weaker and harsher than brown Egyptian
Brazilian...	Pernambuco..	1.50	0.00079	50–70	Warp	Strong and wiry
	Maranham...	1.15	0.00079	50–60	Do.	Harsh and wiry
	Ceara.....	1.15	0.00079	60	Weft	Good, white, and cohesive staple
	Paraiba.....	1.20	0.00079	50–60	Warp or weft	Fairly strong, harsh, of good color
	Rio Grande...	1.15	0.00079	40–50	Weft	Soft, white, and harsh staple
	Maceio.....	1.20	0.00084	40–60	Warp or weft	Soft, pliable, and good for hosiery
	Santos.....	1.30	0.00084	50–60	Weft	Exotic from American seed, white and silky staple
	Bahia.....	.....	.....	40–50	Warp or weft	Fairly strong, but harsh and wiry
American...	Orleans.....	1.1	0.00077	34–46	Do.	Medium length, pearly, white
	Texas.....	1.05	0.00077	32–40	Do.	Similar to above, rather harsher and more glossy
	Allanseed....	1.20	0.00077	50–60	Warp	Good, white, long; blends with brown Egyptian
	Mobile.....	1.00	0.00076	40–50	Warp or weft	Even-running staple, soft and cohesive
	Norfolks.....	1.00	0.00076	40–50	Weft	Used for Oldham counts of 50's
	St. Louis.....	0.90	0.00076	30–32	Warp	Staple irregular, glossy, but short
	Roanokes....	0.90	0.00076	30–34	Do.	A white and strong staple
	Boweds.....	.....	.....	36	Weft	Similar to uplands
	Benders.....	1.10	0.00077	60	Warp	Strong, creamy or white, for Turkey-red dyes
	Memphis....	1.00	0.00077	40–50	Do.	Bluish white, for extra hard twists
	Peelers.....	1.25	0.00077	60–80	Weft	Long, silky, fine staple; adapted for velvets, etc.
	Uplands.....	1.00	0.00077	36–40	Do.	Glossy when clean, apt to be dull, sandy, and leafy

Types.	Variety.	Length, Inches.	Diameter, Inch.	Counts.	Use.	Properties.
American...	Alabama.....	0.90	0.00077	26–30	Warp or weft	Short staple, of less strength, varying color
	Linters.....	.....	.....	8–10	Weft	Short-stapled gin waste
	Tennessee....	0.90	0.00077	28	Warp or weft	Of varying length and color
Greek.....	Smyrna.....	1.25	.....	36–40	Warp	Harsh and strong; adapted for double yarns
African.....	Lagos.....	0.80	.....	20–26	Weft	Dull and oil-stained, irregular in length and strength
West Indian	Carthagena...	1.50	.....	26	Warp	From exotic seeds; fairly strong
	La Guayran..	1.20	.....	40	Warp or weft	Irregular and short, but silky staple
China.....	China.....	1.00	.....	30	Weft	Harsh, short, and white
Australian..	Queensland...	17.5	0.00066	120–200	Warp or weft	Long, white, silky, fine diameter
East Indian.	Oomrawuttee.	1.00	0.00083	26–32	Warp	Short, strong, and white
East Indian.	Hingunghat..	1.00	0.00083	28–36	Weft	Best white Indian staple
	Comptah....	1.05	.....	.....	Warp or weft	Generally dull and charged with leaf
	Broach.....	0.90	.....	28–36	Weft	Like Hingunghat, gives good white weft
	Dharwar.....	1.00	.....	28	Warp	Exotic from American seeds
	Assam.....	0.50	.....	15–20	Warp	White, but harsh, to blend with other cottons
	Bengals.....	0.80	.....	20–30	Warp or weft	Dull and generally charged with leaf
	Bilatu.....	0.50	.....	10–20	Do.	Weak, brittle, and coarse
	Dhollerah....	0.70	.....	15–20	Do.	Strong, dull, and cohesive
	Surat.....	0.60	.....	10–15	Do.	Dull and leafy, often stained
	Scinde.....	0.50	.....	to 10	Do.	Very strong, dull, short, and poor staple

Types.	Variety.	Length, Inches.	Diameter, Inch.	Counts.	Use.	Properties.
East Indian.	Tinnevelly...	0.80	.....	24–30	Do.	Lustrous white, soft, and adapted for hosiery
	Bhownuggar..	1.00	.....	28–30	Warp	White when clean; often leafy and dirty
	Cocoanada...	0.70	.....	10–14	Brown weft	Brown and dull; used as quasi-Egyptian
	Bourbon.....	1.00	.....	30	Weft	Exotic; of good staple; scarce
	Khandeish...	0.80	0.00083	20–26	Warp or weft	Similar in class to Bengal
	Madras or Westerns	0.70	.....	15–20	Do.	Used for low yarns in coarse toweling, etc.
	Rangoon.....	0.60	.....	to 10	Warp or weft	Weak, dull, often stained and leafy
	Kurrachee...	0.90	.. ..	28	Do.	Fairly strong, dull, and leafy
Italian.....	Calabria.....	0.90	.....	26–28	Do.	Fairly strong, irregular and dull, leafy
Turkey.....	Levant.....	1.25	0.00077	36–40	Warp	Harsh, strong, and white

Monie gives the tables on pages 425 to 427 descriptive of the principal commercial varieties of cotton. As the descriptions given in these tables vary, in some respects, quite considerably from the preceding tables of Hannan, it is probably best that both should be given for comparison.

Monie remarks in connection with this table that it will be observed that the Fiji and Tahiti Sea-island cottons are the most irregular in the length of their fibers, the extreme variation in both being half an inch. As long and short cotton never incorporate well together nor adapt themselves to the production of a yarn regular in appearance and strength, it is easy to understand that they are relatively wasteful cottons to work. In any spinning mill where they are used, it will be found that the quantity of " fly," " combings," and " flat waste " made at the various machines is very great, and the reason of this is that in any cotton where the fibers are of different lengths, the long and strong will have a tendency to throw out the short and weak. The cotton which presents the greatest regularity is the Orleans. In comparing the diameters of various cottons with their lengths. it will be found that the longest cottons are usually the finest.

Commercial Name.	Length of Fibers.			Extreme Variation, Inch.	Mean Diameter of Fiber, Inch.	Counts of Yarn.	Class: T = Twist. W = Weft.	Characteristics.
	Max. Inches.	Min. Inches.	Mean, Inches.					
Sea-island	2	1.75	1.87	0.25	0.000635	180–300	T & W	Length and small diameter; silkiness; free from impurities; contains some short and undeveloped fiber
Florida	1.81	1.50	1.65	0.31	0.000637	150–200	Do.	Do. Do. Do.
Fiji Sea-island	2.12	1.67	1.87	0.50	0.000637	150–200	Do.	Similar to preceding, but weaker and containing larger percentage of unripe fiber
Gallini	1.67	1.25	1.43	0.37	0.000675	70–150	Do.	Of a light golden color, very strong and much easier to work into yarn than Sea-island
Peruvian Sea-island	1.75	1.37	1.56	0.37	0.000675	80–140	Do.	Not so fine or silky as Sea-island proper; of a light golden tint; fiber moderately strong; apt to contain much dirt
Tahiti Sea-island	1.75	1.25	1.50	0.50	0.000641	100–130	W	Similar to Fiji in color in appearance, but rather weak, and contains more "neppy" fiber
Brown Egyptian	1.50	1.12	1.31	0.37	0.000738	50–90	T & W	Of a golden color; strong, clean and easy to work
Rough Peruvian	1.44	1.12	1.28	0.31	0.000781	40–70	T	Of a light cream color; feels harsh and wiry; very clean; moderately strong
Smooth Peruvian	1.44	1.12	1.28	0.31	0.000769	40–70	W	Soft, smooth, and pliable; resembles Orleans in color, and in other respects the "rough" variety
White Egyptian	1.37	1.12	1.25	0.25	0.000769	40–70	T & W	Contains considerable broken leaf; color light golden; fibers fairly strong

Commercial Name.	Length of Fibers.			Extreme Variation, Inch.	Mean Diameter of Fiber, Inch.	Counts of Yarn.	Class: T = Twist. W = Weft.	Characteristics.
	Max. Inches.	Min. Inches.	Mean, Inches.					
Pernambuco	1.37	1.12	1.25	0.25	0.000787	40–60	T	Finest of Brazilian crop; similar in color to above; harsher and wirier in staple
Maranham	1.19	0.94	1.06	0.25	0.000787	30–52	T & W	Of a dull golden tint; fibers not so strong as Pernambuco, sometimes quite dirty
Ceara	1.19	0.87	1.03	0.32	0.000787	30–50	Do.	Fairly clean; color dull white; medium strength
Orleans	1.12	0.94	1.03	0.19	0.000757	30–50	Do.	Finest of American white cottons; generally clean; economical to work; fibers soft and moist and to fair strength
Texas	1.12	0.87	1.00	0.25	0.000763	30–50	Do.	Of a light golden tint; other characteristics similar to Orleans
Upland	1.06	0.81	0.94	0.25	0.000763	to 42	W	Similar to Orleans, but somewhat weaker
Mobile	1.00	0.75	0.87	0.25	0.000763	to 36	Do.	Never so clean as either Upland or Orleans, and not quite so strong
Smyrna	1.12	0.87	1.00	0.25	0.000769	to 42	Do.	Color a dull white; fairly clean; of medium strength
West Indian	1.37	1.06	1.22	0.31	0.000769	to 40	T & W	Contains more or less impurities; moderate in strength; fibers rather harsh and dry
African	1.19	0.87	1.03	0.31	0.000819	to 36	T	Of a clear light golden tint. All crops contain some very short fibers, but fairly free from other impurities; moderately strong

Commercial Name.	Length of Fibers.			Extreme Variation, Inch.	Mean Diameter of Fiber, Inch.	Counts of Yarn.	Class: T = Twist. W = Weft.	Characteristics.
	Max. Inches.	Min. Inch.	Mean, Inch.					
Hingunghat	1.19	0.87	1.03	0.31	0.000833	to 36	T	Of a light golden tint; fibers strong, often rather dirty; the finest varieties of Indian cottons
Broach	1.00	0.69	0.84	0.31	0.000833	to 28	T & W	Of a high golden tint; fairly clean; moderately strong
Tinnevelly	1.06	0.69	0.87	0.37	0.000826	26 down	T	Fairly strong; of a dull creamy color; very elastic; moderately clean
Dharwar	0.93	0.69	0.87	0.25	0.000826	to 20	T & W	Fairly clean; much broken fiber; other characteristics similar to Broach
Oomrawuttee	1.06	0.75	0.90	0.31	0.000847	to 20	Do.	Always rather dirty; of a creamy color and strong; fiber regular
Dhollerah	1.06	0.84	0.93	0.25	0.000847	to 20	W	Very dirty; of a whitish color; fibers rather weak
Madras (Western)	1.00	0.75	0.87	0.25	0.000833	to 20	T	Exceedingly dirty and wasteful to work; of a deeper tint than Oomrawuttee and fairly strong
Comptah	1.09	0.75	0.87	0.25	0.000847	to 15	W	Contains much leaf, etc., broken into fine particles; of a brown tint, and fibers rather weak
Bengal	1.00	0.75	0.87	0.25	0.000869	to 15	T	Very dirty; fibers harsh but strong; of a golden tint
Scinde	0.87	0.50	0.65	0.37	0.00084	to 12	T & W	The poorest of commercial cottons; fairly clean; of a dull white color

Höhnel gives the following table for the thickness of different varieties of cotton:

	Thickness in Microns.
North American:	
Sea-island	14
Louisiana and Alabama	17
Florida	18
Upland and Tennessee	19
Southern and Central American	15–21
Average	19
East Indian:	
Dhollerah and Bengal	20
Madras	28
Chinese:	
Nankin	25–40
Egyptian:	
Makko	15
Levantine	24
European:	
Spanish	17
Italian	19

According to Wiesner, the thickest part of the cotton fiber is not directly at the base, but more or less toward the middle (Fig. 190). He gives the following measurements of thickness at different parts of the fiber:

Position.	*G. arboreum*, 25 Mm. Long, Microns.	*G. acuminatum*, 28 Mm. Long, Microns.	*G. herbaceum*, 25 Mm. Long, Microns.
Point	0	0	0
1	8.4	4.2	4.2
2	21	21.6	5.8
3	29	16.8	10.0
4	25	29.4	16.8
5	29	17.0	21.0
6	25	21.1	16.9
7	21	21.1	21.0
Base	17	21.0	16.8
Mean	19.5	16.9	12.5

The length of the cotton fibers attached to a single seed is by no means constant. The longest fibers usually appear at the crown of the seed, while the shortest occur at the base. There is also frequently an undergrowth of very short fuzzy fibers. The cotton seed is more or less egg-

shaped, and the longest fibers occur on the broad end, and the shortest on the narrow end. At the same time, the seed is also covered with an undergrowth of short hairs (2 to 3 mm. in length) which are generally colored yellow, brown, or a dirty green, and are very thin-walled and weak. This undergrowth occurs as a fine down either over the entire seed as in *Gossypium flavidum*, *arboreum*, and *hirsutum*, or merely on the point and base of the seed, as with *G. conglomeratum* and *religiosum*.

In ginning the purpose is not to remove the very short fibers, but at best, more or less of them appear with the ginned cotton. These short fibers are termed " neps," and their presence in any considerable amount

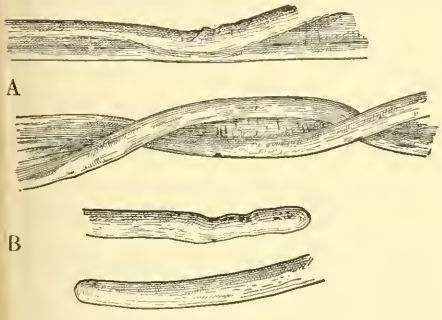


Fig. 190.

Fig. 191.

Fig. 190.—Cotton Fiber. *A*, Middle portions of fiber; *B*, points or ends of fiber.

Fig. 191.—Root of Cotton Fiber. Showing the irregular fracture caused by the fiber being torn from the seed. (Micrograph by author.)

materially affects the commercial value of the cotton. This short undergrowth of neps appears to be made up of incompletely developed or immature fibers, though neps may also arise through excessive breaking of fibers by imperfect manipulation in the carding and spinning processes.

Bowman gives the following table showing the extreme variation in the length and diameter of different kinds of cotton:

Cotton.	Variation in Length, Inch.	Variation in Diameter, Inch.
American (Orleans)	0.28	0.000390
Sea-island	0.39	0.000360
Brazilian	0.28	0.000340
Egyptian	0.22	0.000130
Indian (Surat)	0.25	0.000391

According to the measurements of Wiesner, the average width (diameter of the broadside) of the various kinds of cotton are as follows:

	Microns.
Gossypium herbaceum	18.9
" *barbadense*	25.2
" *conglomeratum*	25.5
" *acuminatum*	29.4
" *arboreum*	29.9
" *religiosum*	33.3
" *flavidum*	37.8

Bowman calls attention to the fact that Egyptian cotton is the most regular in both length and diameter; while Sea-island cotton, though

FIG. 192.—Showing Comparative Lengths of Different Cottons. (Maxima and Minima.) (After Lecomte.)

possessing the greatest length and fineness of staple, also exhibits the greatest variation. It is also noticeable that the variation in the diameter is proportionately very much larger than the variation in the length. Bowman also gives an interesting comparison of the size of the individual cotton fiber with objects of common experience. If a single fiber of American cotton were magnified until it becomes 1 in. in diameter, it would be a little over 100 ft. long, while a Sea-island fiber of the same diameter would be about 130 ft. It requires from 14,000 to 20,000 individual fibers of American cotton to weigh 1 grain, hence there are about 140,000,000 in each pound, and each fiber weighs on an average only

about 0.00006 grain. If the separate fibers contained in 1 lb. were placed end to end in a straight line, they would reach 2200 miles.[1]

Höhnel gives the following table of the different varieties of cotton arranged according to their length of staple:

Gossypium barbadense		(Sea-island)	4.05 cm.
"	"	(Brazilian)	4.00 "
"	"	(Egyptian)	3.89 "
"	*vitifolium*	(Pernambuco)	3.59 "
"	*conglomeratum*	(Martinique)	3.51 "
"	*acuminatum*	(Indian)	2.84 "
"	*arboreum*	(Indian)	2.50 "
"	*herbaceum*	(Macedonian)	1.82 "
"	"	(Bengal)	1.03 "

7. Physical Factors for Cotton Fiber.—Dr. W. L. Ball gives the following interesting data concerning the physical properties of the cotton fiber:

	Sea-island.	Egyptian.	American.	Peruvian.	Average.
Commonest length, inches	2	1.37	1	1.25	
Staple length, inches	2.25	1.75	1.37	1.75	
Ribbon width (mm.$\times 10^{-4}$)	154	194	202	215	191
Weight per cubic meter of hair (mgs.$\times 10^{-5}$)	97	136	171	255	165
Hair break, grams	3.92	4.70	5.04	7.00	5.16

Some calculations from data of dimensions for weight ÷ length: single hair, average denier is 2; tenacity is 2.0 to 3.5 grams per denier (similar to boiled-off silk). Taking the filament of cotton as a cylinder (mean diameter as indicated): 0.2 mgm. to 1 meter length, is equal to 0.315 mm.^{3}, and taking the cotton substance at 1.53 sp. gr., volume of 0.2 mgm. would

[1] Burkett (*Cotton*, p. 328) gives the following data concerning the manufactured value of one pound of raw cotton worth 10 cents:

1½ yards of denim worth 18 cents.
4 yards sheeting worth 20 cents.
4 yards bleached muslin worth 32 cents.
7 yards calico worth 35 cents.
6 yards gingham worth 45 cents
10 yards shirtwaists worth $1.50.
10 yards lawn worth $2.50.
25 handkerchiefs worth $2.50.
56 spools No. 40 sewing thread worth $2.80.

These figures, of course, are only relative averages for the year 1910.

be 0.130 mm.^{3}, or 40 percent, volume of air space would be 0.185 mm.^{3}, or 60 percent. For cotton yarn of 100's count:

Diameter of thread	0.1 mm.
Volume per 10 meters	78.6 mm^3.
Weight per 10 meters	60.0 mgm.

The volume of yarn cylinder represents approximately 50 percent cotton substance and 50 percent air space, and the apparent surface of the yarn cylinder is approximately 550 cm^2.

Pierce [1] gives the following interesting physical factors for individual cotton fibers, taken as an average of a large number of tests:

Variety.	Length, Cms.	Rigidity, Dynes Sq. Cm.	Weight, 10^{-6} Grams.
Sea-island	4.2–5	0.010–0.021	5.9–6.7
Egyptian nubarri	3.6	0.024	6.3
Egyptian affifi	3.1	0.032	5.6
Peruvian hybrid	2.9	0.063	7.7
Trinidad native	2.6	0.045	4.9
Upland Memphis	2.6	0.039	5.3
American FGM	2.4	0.061	5.6
Upland cross	2.3	0.045	5.0
Pernams	2.2	0.071	6.7
Indian Bharat	1.7	0.111	5.8

The rigidity of the fiber is the torque, or twisting force, in the fiber when 1 cm. is given one complete twist.

Pierce also furnishes the following physical factors for the cotton fiber, that may be calculated approximately from the staple length:

Staple length	L (in cms.)
Fiber mass	5.8×10^{-6} grams
Mass per centimeter	$(5.8/L)\times10^{-6}$ grams
Wall cross-section	$(3.9/L)\times10^{-6}$ sq. cms.
Rigidity	$0.3/L^2$ dynes cm.^{2}
Breaking load	$20/L$ grams.
Fibers in yarn section	$1000L/N$ or $(L''/4N)\times10^4$
Initial couple in yarn	$300t/LN=300p/L\sqrt{N}$

The density of the cotton fiber is assumed as 1.51; N is the count of the yarn, L'' is the staple length in inches, t is the twist, and p the spinning factor $t/\sqrt{N}$.

[1] *Jour. Text. Inst.*, 1923, p. 7.

8. Anatomical Structure.—From its behavior with a solution of ammoniacal copper oxide, the cotton fiber appears to consist of four distinct parts structurally. When treated with this solution and examined under the microscope, the fiber is seen to swell, but not uniformly; it seems that at regular intervals there are annular sections which do not swell. The result is that the fiber assumes the form of a distended tube tied at intervals somewhat after the manner of a string of sausages (Fig. 193). Höhnel considers these ligatures as merely parts of the cuticle; he explains their formation by the fiber swelling so considerably as to rupture the undisturbed cuticle, which in places adheres to the fiber in the form of irregular shreds which are visible only with difficulty. In other places where the rupture occurs obliquely to the length of the fiber, the cuticle becomes

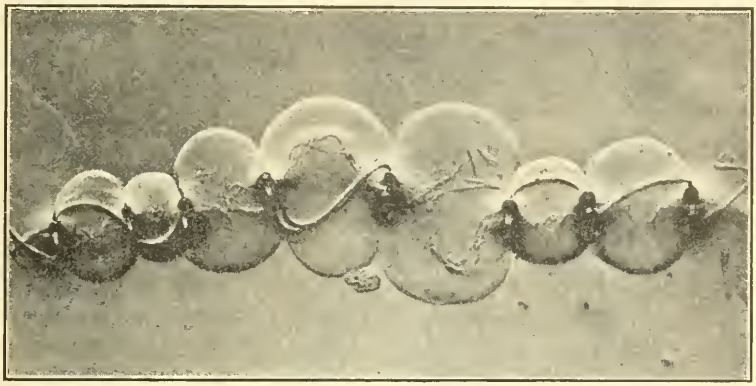


Fig. 193.—Cotton Swollen in Schweitzer's Reagent. (Herzog.)

drawn together in annular bands surrounding the fiber, while between these rings the much-distended cellulose protrudes in the form of globules (Fig. 194). The inner membrane or canal which persists after the rest of the fiber has dissolved is an exceedingly thin tissue of dried protoplasm which was contained in the living fiber.

According to Höhnel, the lumen of cotton is quite small, because the cell-walls of the back and front sides lie close against one another. It is filled partly with air and partly with an exceedingly thin membrane of dried protoplasm which was contained in the living fiber. This membrane, apparently consisting of dried albumen, like the cuticle, remains undissolved after the solution of the cellulose in either ammoniacal copper oxide or concentrated sulfuric acid. As the fiber in dissolving becomes shortened by 40 to 60 percent, its contents assume a peculiar appearance, exhibiting crisscross markings by reason of the folds which are formed.

On bleached cotton the cuticle may be almost entirely lacking, and hence such fibers will not exhibit the characteristic appearance above

mentioned. When the fiber has become much swollen by the action of the reagent it soon begins to dissolve, whereupon the walls of the central canal are seen quite prominently; the dissolving action proceeds rapidly, but apparently there is a thin cuticular tissue surrounding the fiber which resists the action of the solvent for a much longer time than the inner portion. The walls of the central canal also resist the action of the liquid to even a greater extent than the external tissue; the annular contracted ligatures also persist after the rest of the fiber has dissolved. Thus we have four structural parts made evident.

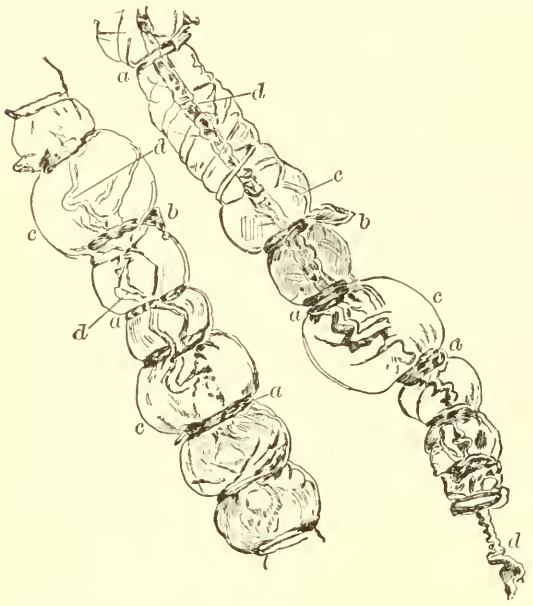


Fig. 194.—Appearance of Cotton Fiber on Treatment with Schweitzer's Reagent. (After Witt.) *a*, Transverse ligatures of disrupted cuticle; *b*, irregular shreds of cuticle torn apart; *c*, swollen mass of cellulose; *d*, walls of internal canal.

(*a*) The main cell-wall, probably composed of pure cellulose, and rapidly and completely soluble in the reagent.

(*b*) An external cuticle, probably of modified cellulose, and more resistant to the action of the reagent.

(*c*) The wall of the central canal, which resists the solvent power of the reagent even more than the cuticle.

(*d*) The annular ligatures surrounding the fiber at intervals, which persist even after the canal-walls have dissolved.

The cuticle cannot always be seen in an equally distinct manner, because it may occur thinner or thicker, smooth or rough. The thinnest and smoothest is to be found on Sea-island cotton, which comes from *Gossypium barbadense;* while the coarse varieties of cotton, such as *Gossypium flavidum, arboreum, herbaceum,* and *religiosum,* possess a hardy, roughly granular cuticle. With this is connected the fact that the latter-mentioned varieties of cotton yield a dull-looking fiber. A very remarkable thing is the granulation of the cuticle by the action of the air. The stripes and other structural relations which are to be noticed on the cotton fiber originate principally in the cuticle. The cellulose membrane itself shows no spots of any kind and no other structural peculiarities. On well-

bleached cotton material (yarn, cloth, etc.) the cuticle may be almost entirely lacking. For extended areas over the fiber the cuticle may not be found at all, and hence does not yield the characteristic phenomena above mentioned when the fiber is swollen up with ammoniacal copper oxide solution.

O'Neill (in 1863) first pointed out this complex structure of the cotton fiber. He says: "I believe that in cotton-hairs I could discern four different parts. First, the outside membrane, which did not dissolve in the copper solution. Second, the real cellulose beneath, which dissolved, first swelling out enormously and dilating the outside membrane. Thirdly, spiral fibers, apparently situated in or close to the outside membrane, not readily soluble in the copper liquid. These were not so elastic as the outside membrane and acted as strictures upon it, producing beadlike swellings of a most interesting appearance; and fourthly, an insoluble matter, occupying the core of the cotton-hair, and which resembled very much the shriveled integument in the interior of quills prepared for making pens." He also notes that the insoluble outside membrane was not evident on bleached cotton, hence concluding that either it had been dissolved away, or some protecting resinous varnish had been removed, and then it became soluble. He also obtained the same general results by treatment with sulfuric acid and chloride of zinc in place of the ammoniacal copper oxide solution.

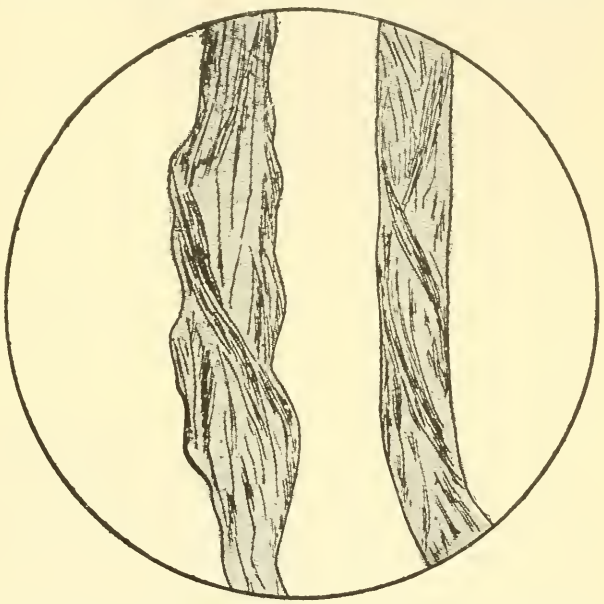


FIG. 195.—Cotton Fiber Swollen with Schweitzer's Reagent. (×600.) Showing spirally developed lamella in fiber walls. (Micrograph by author.)

According to Butterworth, who observed the cotton fiber treated with the ammoniacal copper oxide solution under a magnification of 1600 diameters, there are spiral threads (Figs. 195 and 196) apparently crossing and tightly bound round the fiber at irregular distances, also spiral threads

passing from one stricture to another; the core of the fiber has a spiral form, and in cross-section shows the presence of concentric rings.

There appears to be some difference in the action of ammoniacal copper oxide solution on fibers of different physiological structure. Immature or unripe fibers dissolve readily without exhibiting any structural differences. The tubular-shaped fibers swell out as a whole and finally dissolve without showing any structural modifications, except that in many cases an inner core is left.

Minajeff [1] has studied the structure of cotton as shown by the action of concentrated caustic soda solution on the fiber, particularly with reference to the question of mercerisation. His conclusions may be summed up as follows: (1) The cuticle of the raw fiber withstands the action of concentrated cuprammonium solution, also strong sulfuric acid and alkalies. The cuticle of the fiber shows the same properties, but less pronounced, while that of the oxidised fiber is weak and brittle. (2) The fiber wall swells and dissolves in cuprammonium solution, also in concentrated sulfuric acid, with the formation of amyloid-like bodies. (3) The inner protoplasmic lining is very similar in its reactions to the cuticle.

Examination with the highest microscopic powers has not shown any cellular structure pertaining to the cellulosic contents of the cotton fiber; it is apparently composed of fine layers of spirally laid fibrillæ superimposed one upon the other.

The spiral fibrillæ occurring in the cell-wall of the cotton fiber can be readily observed under the microscope with even moderately high magnification in the case of cotton rag pulp for paper manufacture. The cotton fibers under these circumstances have been so broken up and mechanically bruised and partially disintegrated that the individual fibrillæ are often well separated. Kuhn concurs with the author in the opinion that the cotton fiber is made up of spirally laid fibrillæ, and he attributes the absorptive power of cotton toward solutions to the permeable spaces occurring between these fibrillæ. Bowman [2] also calls attention to this structure. This opinion, however, is not held by Balls,[3] who made a very extensive investigation on the structure of the cotton fiber with relation to its development and growth. He states that the concentric layers of cellulose, probably delimited from night to night, are laid down on the interior of the delicate cellulose cuticle wall, until a definite thickness is reached. Using a swelling reagent on cotton taken from dated bolls, Balls was able to prove definitely the presence of these rings up to the number of 25, with an average thickness of about 0.4 micron each, corresponding with the number of days from the cessation of growth in length.

[1] *Zeit. Farben-Ind.*, 1907, pp. 233, 252, 309, 345.
[2] *Structure of Cotton Fiber*, p. 105.
[3] *The Cotton Plant in Egypt*, p. 84.

He accounted for their differentiation from each other by reference to the arrest of growth by the "sunshine effect" occurring in the middle of each day in Egypt. This spiral structure of the cell-wall of the cotton fiber is in disagreement with the statement of De Mosenthal [1] who claims that the cellulose of cotton consists of minute spherical granules about 1 micron in diameter. All the best authorities on the microscopy of cotton, however, are opposed to this view of its structure.

FIG. 196.—Portion of Fig. 195 more Highly Magnified. (×1500.) The spiral structure of the cotton cellulose is here plainly visible. (Micrograph by author.)

According to Dreaper [2] the outer sheath of the cotton fiber is considered to be pure cellulose, while the inner layers are made up of secondary cellular deposits; or are formed by a gradual thickening of the outer layer.

FIG. 197.—Sea-island Cotton. (×185.) (Herzog.)

Whether the substance which is present in the outer wall of cotton can be included under the generic term of cutin is a problem for chemistry. Its exact nature is unknown, and research on the subject is awaited. It is certainly of a waxy or fatty nature, resistant to acids and cellulose solvents, while susceptible to the action of alkalies, which are said by

[1] *Jour. Soc. Chem. Ind.*, 1904, p. 292.

[2] *Chemistry and Physics of Dyeing*, p. 12.

Haller[1] to cause its disappearance in the process of mercerisation. The cuticle has long been recognised as very liable to mechanical damage, and hairs taken from a yarn show frequent abrasions and cracks; a fact commented on by Butterworth in 1881, and since apparently overlooked. Such abrasions are visible in dry cotton under quite a low magnification by reflected light, as bright patches with an almost granular appearance, while cracks due to pressure can best be seen under a higher power if the specimen is mounted in a suitable medium.

One feature in the structure of the cotton fiber which has been the subject of much discussion, and which at the same time is of great importance in the dyeing and bleaching of the fiber, is the occurrence of pits or openings in the cell-wall. Cracks, running more or less spirally along the cuticle, have been seen by several observers, and can be produced at will by mechanical ill-treatment of the hair. Definite pores in the cuticle have, however, been observed by Mosenthal.[2] These pits or pores, to which he gave the unfortunate name of Stomata, are described by him as occurring in oblique rows as if they led into oblique lateral channels.

Fig. 198.—Upland Cotton. (×185.) (Herzog.)

It is usually accepted that the cellulose composing the primary wall is chemically distinct from that of the secondary deposition. While the exact relation of the cutinous substance to the wall is not known, whether, for instance, it is dispersed through its mass, or merely forms an external coating (which from the behavior of the cuticle in cuprammonium seems likely) there is evidence to prove a profound change in the chemical composition of the cell sap at the time when elongation in length ceases and secondary growth begins. The young hairs are extremely astringent, and possibly contain tannins, as they turn black when immersed in a solution of a ferric salt, whereas the ripe hairs do not.

[1] *Text. u. Färberei Zeit.*, 1907, p. 221. [2] *Jour. Soc. Chem. Ind.*, 1904, p. 292.

9. Microscopy of Cotton Fiber.—The microscopical characteristics of the cotton fiber are so pronounced as to differentiate it readily from all others. As previously noted, it presents the appearance of a flat, ribbon-like band, more or less twisted on its longitudinal axis (Figs. 197, 198, and 199). The edges of the fiber are somewhat thickened, and usually present irregular corrugations. The fiber also at times presents the appearance of a rather smooth flat band with little or no thickened edges. According to Höhnel, the cotton fiber appears as a broad, finely grained band, which is repeatedly twisted about its axis. In this case, the walls are relatively thin, the fiber is from three to four times as broad as it is thick, and the lumen is three to four times as broad as the walls. This is essentially all to be observed in the case of ordinary coarse varieties of cotton (for example, the Indian) the maximum diameter of which is 30 mm. In the case of finer varieties (North American, Egyptian), especially from *G. barbadense*, the fiber appears only slightly or not at all compressed, only slightly twisted in a rope form, relatively very thick-walled so that only a narrow lumen is seen. Hence the fiber looks as if it possessed glossy, thickened edges. Often such kinds of cotton are almost cylindrical for considerable distances along their length, and in some measure resemble linen fibers.

FIG. 199.—Indian Cotton. (Herzog.)

The twist of the fiber does not appear to be continuous in one direction; a portion of a fiber may be twisted axially to the right, then exhibit a flattened portion without any twist at all, then again show an axial twist to the left. The twist of the cotton fiber appears to be a character acquired through cultivation, as it is not possessed by wild cotton. Monie [1] explains the twist in cotton as follows: The rotary motion begins with the process of vacuation in the fiber, caused by the withdrawal of some of the fluid in the fiber when the seed begins to ripen, and as this is affected slowly and progressively, beginning at the extremity farthest from the seed and

[1] *The Cotton Fiber*, p. 25.

gradually receding toward the base, the free end or point becomes twisted on its own axis several times, thus producing the convoluted form exhibited under the microscope.

According to Hanausek [1] the greater the number of twists in a given length of the fiber and the greater the regularity of these twists, so much the greater is the commercial value of the cotton. The correctness of this statement, however, is disputed by Herbig. For about three-fourths of its length the fiber maintains a comparatively uniform diameter, then it gradually tapers to a point, where it is perfectly cylindrical and often solid (Fig. 190).

In some cases portions of a fiber may exhibit cylindrical and apparently solid spaces, doubtless caused by irregularities in the growth of the cell. At these places the strength of the fiber is weakened, and will not absorb solutions to the same degree as the rest of the fiber. The cell-wall is rather thin and the lumen occupies about two-thirds of the entire breadth and shows up very prominently in polarised light. Between its thickened edges the fiber exhibits the appearance of a finely granulated surface.

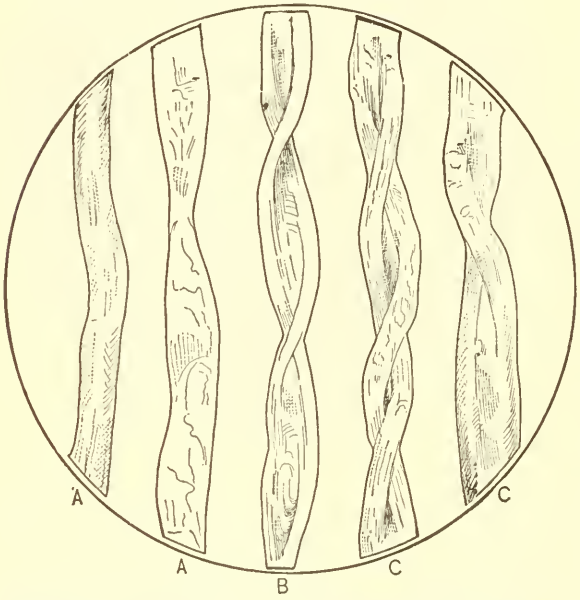


FIG. 200.—Cotton Fibers. (×500.) Longitudinal views.

Fibers of dead cotton, or those which have not reached their full maturity, are seldom twisted spirally and do not have a lumen, but are thin, transparent bands (Fig. 185). Unripe cotton therefore has not much value for purposes of manufacture, as it contracts and curls up in the warm atmosphere of the mill, and consequently yarn containing much unripe fiber depreciates considerably.

Denham points out that the lumen of the cotton fiber contains in a dead and desiccated state the remains of the protoplasm and the nucleus which were responsible for its growth. While the luster of the fiber seems

[1] *Microscopy of Technical Products*, p. 61.

to be dependent on the cuticular surface and the convolutions, the color is largely dependent on the contents of the canal, which on this account have received the label "endochrome," though this should strictly be confined to the coloring matter itself. Curiously pigmented forms, such as "Khaki," "Blue Bender," and "Texas Wool," the last a bright green, occur from time to time, as do many less brightly colored "rogues," and many varieties have a strongly colored fuzz.

Microscopically cotton fibers differ considerably among themselves, but in general may be divided into four classes:

(*a*) Fibers exhibiting a smooth, straight, flat appearance with no suggestion of internal structure. These include immature cotton fibers and also fibers which have over-ripened. The external wall of the fiber is very thin.

(*b*) Fibers exhibiting a normal appearance through some portions of their length, and in other parts a structureless appearance as in (*a*). These may be termed "kempy" fibers; the solid, tubular portion of the fiber is particularly resistant to the absorption of liquids and dyestuffs, and consequently remains uncolored while the rest of the fiber is dyed.

(*c*) Straight, tubular fibers exhibiting a well-defined internal structure and a transparent cell-wall of varying thickness. Fibers of this character may often be mistaken under the microscope for linen, especially if the cell-wall is thick. The fibers of *Gossypium conglomeratum* are especially liable to show this form.

(*d*) Normal structure of twisted, band-like form.

In cross-section the immature fibers show only a single line with no structure (Fig. 201, *A*), and but little or no indication of an internal opening. The mature fiber is thicker in cross-section and exhibits a central opening (Fig. 201, *B* and *C*).

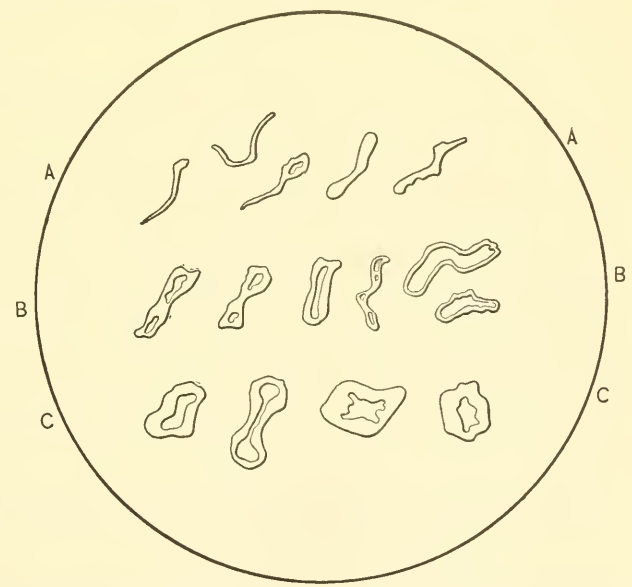


Fig. 201.—Cross-sections Cotton Fibers. (×500.) *A*,*A*, unripe fibers; *B*,*B*, half-ripe fibers; *C*,*C*, fully-ripe fibers.

Haller[1] in describing the microscopic appearance of cotton, distinguishes three parts, the cuticle, the cell membrane, and the

[1] *Zeit. Farb. Chem.*, 1907, p. 125.

lumen. The cuticle, consisting of "cutinised cellulose," has a finely grained or fibrous structure, is insoluble in ordinary cellulose solvents but soluble in strong alkalies, and is resistant to boiling under pressure with lime or even with sodium hydroxide of 2° to 8° Tw. It is, therefore, so Haller considers, very doubtful whether the "cutin" in the cuticle is a fat as suggested by Wiesner. The cell membrane, consisting of almost pure cellulose, is more or less colored, the pigment being resistant toward common solvents, but destroyed by long contact with oxidising agents. The membrane is soluble in ammoniacal copper hydroxide solution ("cuprammonium"), treatment with this reagent leaving the cuticle and inner skin hanging in shreds. The lumen contains dried protoplasm, which extends also into the adjacent layers of the membrane. The protein is rendered visible by staining with Safranine, the hairs being steeped in a solution of the dye in dilute acetic acid, and then washed with water and boiling alcohol, when the reddened fiber has been treated first with "cuprammonium." Haller suggests that in mercerised cotton the cuticle is entirely lacking, and that in dyed unmercerised cotton the color is only absorbed on the surface, while on mercerisation penetration occurs, this accounting for the deeper colors. In a later paper[1] he concludes that the outer membrane consists of two structural elements which show little difference under normal conditions but are readily differentiated when the cellulose is transformed into oxy- or hydro-cellulose.

Levine,[2] by chemical and bacteriological treatment followed by microscopic examination, draws the conclusion that there are five structural elements involved: (*a*) the outer layer or integument, which is the encrusting layer and forms the cementing material of the fiber, being a mixture of cutinous, pectinous, gummy, fatty, and other components; (*b*) the outer cellulose layer, a distinct spiral comprising a limited number of components, perhaps one or two, and possibly consisting of impure cellulose; (*c*) the secondary layer of deposits, made up of components which in no case have a spiral structure and are 5 to 10 in number; (*d*) the wall of the lumen, a spiral much the same as the outer layer, but differing in chemical composition; (*e*) the lumen, the substance of which is structureless and nitrogenous. The evidence on which the conclusions are based is not detailed.

A comparative study of the materials for making cellulose esters has led Noyer[3] to suggest that the cuticle consists of oxycellulose, which is porous, has great osmotic properties, and is not acted upon by esterifying agents, but allows these to penetrate into the fibrils by osmosis.

[1] *Kolloid Zeitsch.*, 1907, p. 127.
[2] *Science*, 1914, p. 906.
[3] *Caoutchouc & Guttapercha*, 1913, p. 703.

10. Microchemical Reactions.—The most characteristic of the microchemical reactions for cotton is that with ammoniacal copper solution, previously described. With bleached cotton the external cuticle may be absent, and hence such a fiber may not show any distention. With iodine and sulfuric acid the cotton fiber becomes blue in color, though the cuticle remains colorless.[1] Tincture of madder gives an orange color; fuchsine produces a red color which is destroyed by the addition of ammonia. Flax does not show this latter reaction, hence this serves as a chemical means of distinguishing between cotton and linen, provided the linen is unbleached. Bleached linen shows practically no differences from cotton in its chemical tests. Anhydrous stannic chloride gives a black color with cotton, and sulfuric acid dissolves the fiber rapidly.

Cross-sections of the cotton fiber may be prepared by arranging a number of fibers in parallel rows in glycerol-gum, allowing the gum to harden by drying and then cutting a section with a suitable microtome. The glycerol-gum is prepared from 10 grams of gum arabic, 10 cc. of water, and 45 to 50 drops of glycerol. The sections should be examined in water, and again after treatment with iodine-sulfuric acid reagent. This causes the sections to swell to broadly elliptical or irregular forms without altering the shape of the lumen, the cell-wall is colored blue, while the cuticle which is distinctly evident as a delicate line, is colored yellow, as are also the cell-contents.

11. Physical Properties; Spinning Qualities.—The natural, spiral-like twist present in the cotton fiber causes the latter to be especially adaptable to purposes of spinning. The spinning qualities of the cotton fiber, however, depend not only on the nature and amount of twist which causes the individual fibers to lock themselves firmly together, but also on the length and fineness of staple. These three qualities in general will determine the character and fineness of yarn which may be spun from any sample of cotton. Sea-island cotton lends itself to the spinning of very fine yarns, being spun to even 300's (that is, 300 hanks of 840 yds. each would weigh 1 lb.), and in an experimental manner this cotton is said to have been spun as fine as 2000's.

Kuhn [2] states that wild varieties of cotton show a decreased number and uniformity of twists than cultivated species, and the relapse of a cultivated variety into a wild state is always accompanied by a lessened development of twist in the fiber. Kuhn is of the opinion that in the

[1] In the raw cotton fiber, however, the coloration is liable to be rather pale or purplish, and on various parts of the surface there are to be seen dark yellow plates or spots caused by the encrusting materials on the raw fiber. The inner canal also frequently contains granular protoplasmic substances that give a dark yellow color. In fact it has been claimed that these characteristics are sufficient to distinguish between fibers of raw and bleached cotton.

[2] *Die Baumwolle*, p. 122.

wild plant the fibrillæ of which the cell-wall of the fiber is composed, tend to assume a more spiral formation, which causes the fiber to become more rigid and less elastic and prevents the production of twists. Cultivation tends to make the constituent fibrillæ assume a position more parallel to the axis of the fiber, which makes the latter more elastic so that it more readily lends itself to the formation of twists.

In the spinning of cotton yarns two general classifications are made: (*a*) *carded*, and (*b*) *combed* yarns. Carded yarns are prepared from the shorter stapled varieties of cottons, and, as a rule, are only spun in com-

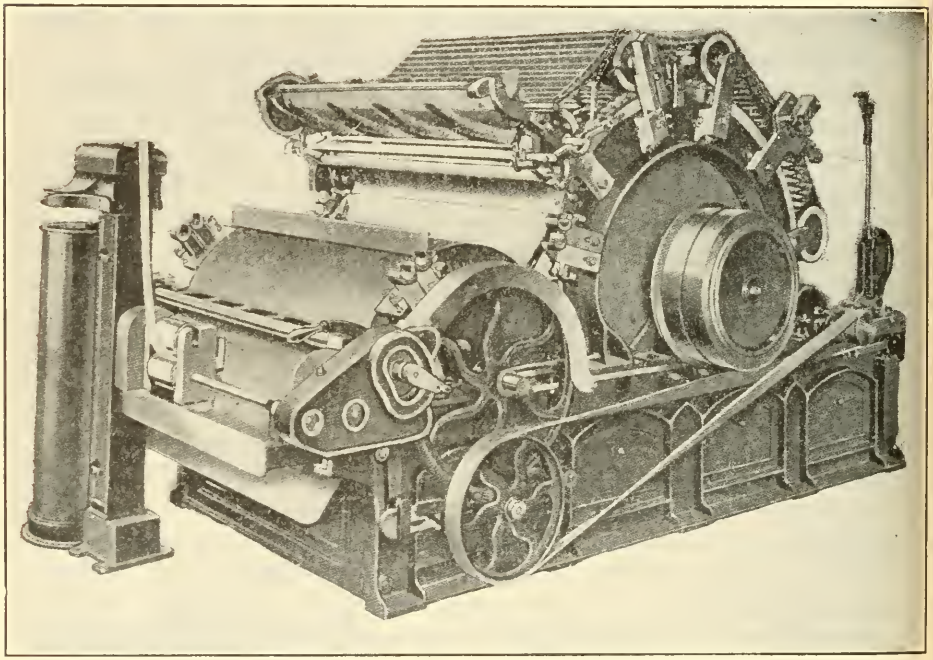


Fig. 202.—Revolving Flat Cotton Card. (Whitin Mch. Wks.)

paratively low counts (under 80's). Combed yarns are made from the longer stapled cottons, and for this purpose it is necessary to comb out or eliminate the shorter fibers occurring in the cotton. This is done by means of the cotton comber which has the purpose of extracting all fibers having less than a certain length, so that the combed sliver consists principally of the long fibers. The fibers in this sliver are also much more uniform in length than those of carded cotton, and these two conditions have much influence on the quality and appearance of the finished yarn, making it stronger and smoother. In the combed yarn more advantage is taken of the strength of the individual fiber itself, whereas in yarns spun from shorter staples and of varying lengths of fibers, the tensile strength

of the yarn depends principally on the resistance to breaking offered by the cohesion of the interlocked fibers. This cohesion or clinging is due to the natural convolutions or twists in the fiber accentuated, of course, by the twisting of the fibers about one another in the spinning of the yarn. The smoothness of the combed yarn is due to the fact that the fibers lie parallel to each other and to the direction of the yarn. In carded yarns, on the contrary, the shorter fibers lie in many directions and many of the ends of the shorter fibers protrude from the yarn, making it uneven and lumpy. It is also necessary to give more twist to carded yarns in order to obtain the desired strength. The elimination of the short fibers in combed yarns also permits of much more uniformity in spinning, and this naturally

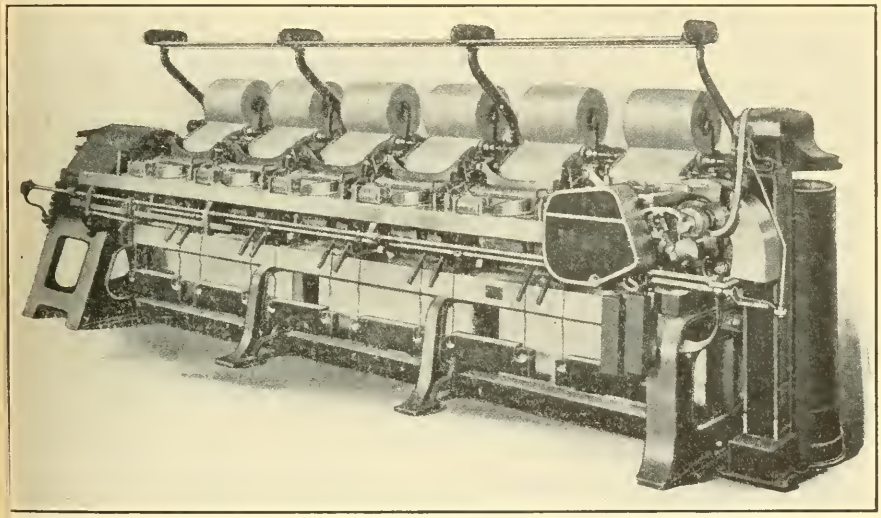


Fig. 203.—Cotton Comber, Nasmith Type. (Whitin Mch. Wks.)

minimises the occurrence of thick and thin places in the yarn. Combed cotton, owing to the action of the needles in the comber, has much greater parallelisation of the fibers, and on this account the yarn has much more luster than carded yarn. There is also much less impurity in combed yarns, the comber cleaning the fiber very thoroughly.

12. Tensile Strength.—In its tensile strength cotton stands between silk and wool; whereas, in elasticity, it is considerably below either of the other two fibers. The breaking strain of the single fiber of cotton will vary from 2.5 to 10 grams, depending on the fineness of staple; the finer the fiber the less will be its breaking strain.

The following table shows the results of experiments on the tensile strength of different varieties of cotton:

Cotton.	Mean Breaking Strain.	
	Grains.	Grams.
Sea-island (Edisto)	83.9	5.45
Queensland	147.6	9.59
Egyptian	127.2	7.26
Maranham	107.1	6.96
Bengal	100.6	6.53
Pernambuco	140.2	9.11
New Orleans	147.7	9.61
Upland	104.5	6.79
Surat (Dhollerah)	141.9	9.22
Surat (Comptah)	163.7	10.64

Lecomte gives the following table showing the breaking strain of various cotton fibers.

Cotton.	Breaking Strain. Grams.
New Orleans	9
Texas	6.6
Peru (harsh)	10.5
Peru (long, silky)	4.1
Sea-island	8
Port-au-Prince	9.5
Haiti	5.1
Tahiti	4.9
Egyptian (brown)	7.6
Bengal	4
Tinnevelly	3.2

The following table exhibits the comparative values of the tensile strength of different fibers. The "breaking length" refers to a length of thread which will break by reason of its own weight.

Fiber.	Breaking Length in Kilometers.	Tensile Strength, Kilograms per Square Mm.
Cotton	25.0	37.6
Wool	8.3	10.9
Raw silk	33.0	44.8
Flax fibers	24.0	35.2
Jute	20.0	28.7
Ramie	20.0	28.7
Hemp	30.0	45.0
Manila hemp	31.8	47.7
Cocoanut fiber	17.8	29.2
Vegetable silk	24.5	35.9

The full tensile strength of the individual fiber, however, is not utilised in the spun yarn. Single yarns will give only about 20 percent, or one-fifth, of the breaking strain calculated from the strength of the separate fibers; two-ply yarns give about 25 percent. Herzfeld [1] gives the following table showing the strength in grams of single cotton yarns of different counts, the numbering of the yarns being according to the metric system:

No.	Weak.	Medium.	Strong.	Very Strong.	No.	Weak.	Medium.	Strong.	Very Strong.
4	880	1000	1250	....	32	125	170	200	250
6	670	920	1080	1340	34	120	160	190	220
8	500	690	810	1000	36	110	150	180	210
10	400	550	650	800	38	105	140	170	200
12	330	460	540	660	40	100	135	160	190
14	285	390	460	570	50	....	110	130	140
16	250	340	400	500	60	....	90	110	125
18	220	300	360	440	70	....	80	90	105
20	200	280	320	400	80	....	70	80	95
22	180	250	295	360	90	....	60	70	85
24	170	230	270	330	100	....	55	65	80
26	150	210	250	310	110	....	50	60	70
28	140	200	230	290	120	....	45	55	60
30	130	180	215	260					

Monie also gives a table showing the strength of cotton fibers after manufacture into yarn in relation to those in their natural condition.

Carded Cotton

Description of Yarn.	Average Number of Fibers in Cross-section of Yarn.	Test Strength of Each Fiber in Grains.	Calculated Strength of Yarn in Pounds.	Actual Strength of Yarn in Pounds.	Percentage of Strength Utilised.
32's twist American cotton.....	120	140	200	49.5	24.7
36's " " "	110	140	176	40.0	22.7
40's " " "	100	140	160	36.0	22.5
46's " Egyptian cotton.....	132	146	220	52.0	23.6
50's " " "	110	146	184	46.0	25.0
60's " " "	100	146	167	33.5	20.6
70's " brown Egyptian cotton..	74	150	127	27.5	21.6
80's " " " " ..	60	150	103	23.5	22.8

[1] *Yarns and Textile Fabrics*, p. 95.

Combed Cotton

80's twist Egyptian cotton.....	90	120	100	25	20.3
120's " " "	55	120	66	18	24.2
120's " " "	50	120	68	15	22.0
143's " " "	40	120	55	13	23.6
165's " Sea-island cotton.....	45	100	55	13	25.4
190's " " "	38	100	43	10.5	24.4

The following table shows the breaking length and corresponding elasticity (elongation sustained under the breaking strain) of yarns from various fibers:

	Breaking Length in Kilometers.	Elasticity.
Cotton yarn.....	13–14	3.97
Ramie yarn.....	11–12	0.8–1.8
Flax yarn (wet spun).....	12–20	1.1–1.8
" " (dry spun).....	11–12	2.5–3.7
Jute yarn.....	9.9	2.0
Artificial silk.....	12.0	2.0
Wood pulp yarn (Silvalin).....	5.5	6.8

In determining the breaking strength of cotton fabrics or yarns attention must be drawn to the influences of varying amounts of moisture in the material, and in making comparative tests care should be taken that the samples are tested under the same hygroscopic conditions. Scheurer [1] gives the following results showing the influence of moisture on the tensile strength:

	Relative Strength.
1. Cloth containing normal moisture.....	100
2. Same cloth made perceptibly damp with water.....	104
3. Same cloth dried and tested warm.....	86
4. Same cloth completely moistened with water.....	103

Greenwood [2] has made an exhaustive study on the effect of certain industrial processes on the strength of cotton fibers and yarns. Cotton was spun from selected Egyptian cotton and samples of the yarn were submitted to the following tests: two-ply (1) gray, (2) gray mercerised, (3) bleached, (4) mercerised and bleached, (5) gray gassed, (6) gray gassed and mercerised, (7) gassed and bleached, (8) gassed, mercerised and bleached, (9) mercerised without tension. Also singles (1) gray, (2) gray

[1] *Bull. Soc. Ind., Mulh.*, 1902.

[2] *Jour. Textile Institute.*

gassed, (3) scoured, (4) bleached. A large number of tests were made at a constant humidity of 70 percent. It was found that the various processes up to and including spinning have no detrimental effect on the strength of the individual fibers. If the final count is not considered, the effect of gassing was contradictory; mercerising strengthened the yarn in all cases, but the strength of the fibers remained the same. Bleaching strengthened the yarn in nearly all cases, but weakened the fibers. Each of the processes increased the breaking strength of the yarn. From this study it would appear that a yarn realises more of the available fiber strength than has been previously assumed. The increased yarn strength is to be attributed to the greater cohesion of the fibers. It is also suggested that the increased strength of the yarn after bleaching is due to the removal of the natural wax which tends to act as a lubricant.

13. Methods of Determining Tensile Strength of Fibers.—There have been a number of machines devised for the purpose of determining the tensile strength and elasticity of fabrics and yarns, and a few instruments have also been adapted for the testing of single fibers. As the individual fiber, however, is a very slender and delicate object, especially in the case of certain vegetable fibers, the determination of its physical factors is an operation which requires a delicately adjusted apparatus. In machines which require the taking on or off of weights, the jar is usually sufficient to break the fiber before its true breaking strain is reached. The same criticism is also true for machines employing water as a weight. A machine devised by the author has proved very satisfactory for determining the tensile strength and elasticity of almost any fiber, from very fine and delicate filaments to coarse and strong hairs.

A diagrammatic drawing of this machine is given in Fig. 204. The fiber to be tested is clamped between the jaws at J, the pointer attached to the end of the beam above the upper jaw being brought to the zero-mark on the scale S, while the lower jaw is raised or lowered in its stand until the desired distance between the jaws is obtained. To obtain comparable results this distance should always be the same; and 10 cm., in the case of long fibers, or 2 cm. for short fibers, have proved to be good lengths of fiber to test. The sliding-bar R is moved forward by turning the rod T, which moves the rack and pinion at P, until the graduation on the wheel G is at zero to the indicator. Under these conditions there is no strain on the fiber. A stretching force is then placed on the fiber by moving the bar R backward by turning the rod T; the motion of this bar is made uniform and gradual until the fiber finally breaks under the strain thus placed upon it. The graduation on the wheel G will then indicate in decigrams the breaking strain of the fiber being tested. The elasticity is obtained by watching carefully the pointer moving up the scale of millimeters at S until the rupture of the fiber takes place; the

distance this pointer moves represents the actual stretch of the fiber, and if the length of fiber taken between the jaws is 10 cm., this figure will represent directly the percentage of elasticity. If the length of fiber taken is only 2 cm., to obtain the percentage of elasticity it is necessary to multiply the amount of stretch in millimeters by five; and for other lengths of fiber similar proportions will hold. The weight *W* at the rear end of the beam can be moved backward or forward, and is for the purpose of adjusting the balance so that there is no strain at *J* when the indicator on *G* marks zero. The wheel *G* is graduated in decigrams, and this marks the sensibility of the machine; the total graduations on *G* running from zero to 400. When fibers are tested having a greater tensile strength

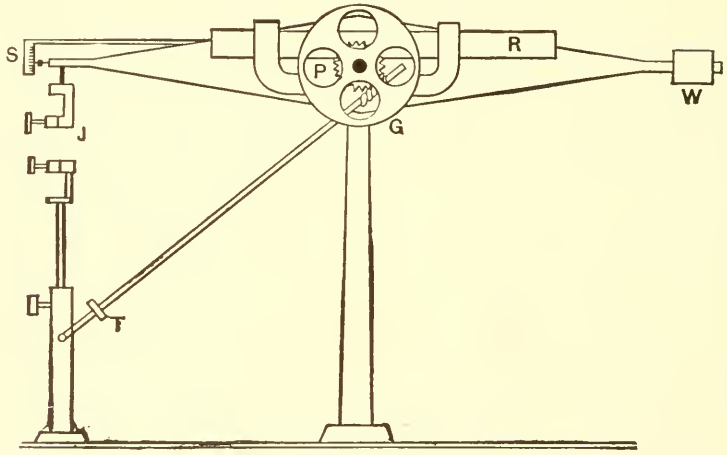


FIG. 204.—Fiber-testing Maching.

than 400 decigrams a fixed additional weight of 10, 25, 50, etc., grams may be hung from *W*, and this must be added to the reading on the wheel when the fiber breaks. If the elasticity of the fiber is so great as to carry the pointer beyond the limits of the scale at *S*, a shorter length of fiber must be tested. A fair average of breaking strain and elasticity may be obtained for any quality of fiber by testing about ten separate fibers and taking a mean of the total tests. If the quality of the fibers, however, in a sample does not run very uniform, it is best to increase the number of tests to twenty-five or even fifty in order that a satisfactory average may be obtained.

The Bureau of Plant Industry at Washington has made quite extensive tests on the tensile strength of cotton fibers by the use of a machine of the same character as that above described. In making the tests the single fiber is picked up with a pair of forceps and placed in the

jaws of the machine, the rounded faces of which, pressed together with springs, hold the fiber firmly but do not cut it. The weight is then added by turning the thumbscrew with a uniform motion, and the breaking strain is read on the dial in $\frac{1}{10}$ gram; twenty fibers were broken, one at a time, and the average determined as the breaking strength of the sample. While there is much variation in every sample, it has been found by numerous trials that the average breaking strain of twenty fibers is approximately the same as that for a larger number of fibers. This is especially true of seed cotton, where it is possible to take one fiber from each of twenty samples. Furthermore it was found that the fibers taken from midway on the side of the seed are more uniform than those at either end; those at the pointed end are most variable. The results from a large number of tests from nearly all of the prominent varieties of the seven different groups of American Upland cotton, and also Sea-island and Egyptian cottons, are given in the following table:

TENSILE STRENGTH OF COTTON FIBERS

Variety of Cotton.	High, Grains.	Low, Grains.	Average, Grains.
American Upland:			
Big-boll stormproof group	139	80	103
Big-boll group	179	71	102
Cluster group	119	79	92
Semicluster group	109	72	90
Peterkin group	92	77	88
Early group	106	80	87
Long staple group	86	54	73
Sea-island	117	72	95
Egyptian:			
From Arizona and California	123	86	103

The highest and lowest figures given in the foregoing table are the averages for twenty fibers, not the highest and lowest breaking strain of single fibers. The tensile strength of single fibers of American Upland cotton is generally in inverse ratio to their length, though the longer staples make stronger yarns. The strength is in more direct ratio to the diameter. The accurate measurement of the diameters of the twisted, ribbonlike cotton fibers presents such difficulties and requires so much time that it is not included in all tests.

A series of tests has also been made to determine the pull necessary to detach the fiber from the seed. In American Upland varieties this ranges from 29.0 to 35.5 grains, and in Sea-island from 27.0 to 30.1 grains.

Barrett (*Jour. Textile Institute,* 1922) describes an apparatus and method for the testing of single fibers for tensile strength and elasticity, the basis of which is a small Oertling balance. The pans are removed and replaced by: (*a*) On the right—a bundle of magnetised steel piano wires, hung vertically, with half its length inside a solenoid of covered copper wire through which an electric current can be sent, and accurately measured by means of a sensitive ammeter; (*b*) on the left—a small weight, in order to counterbalance the magnet on the right. An auxiliary knife edge *E* (Fig. 205) is constructed, and rigidly clamped about half-way along the left arm of the balance. Suspended from this edge, but easily removable, is a special clamp, *FNA*, to hold the end *A* of the fiber to be tested. The other end, *B*, of the fiber *AB* can be clipped vertically below this in another adjustable clamp *BC*, which is attached firmly at *C* to the central pillar of the balance. The fiber *AB*—usually of length 13.5 mm.—is mounted by means of bicycle cement in small double paper squares.

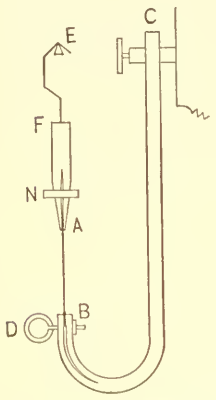


Fig. 205. — Barrett's Apparatus for Testing Single Fibers.

The fiber is first inserted at *A*, the nut *N* pushed upward into position to grip the paper square, and the clamp *FNA* hung on the knife edge *E*. The adjustable clamp *B* of the attachment *BC* is moved into position vertically below *A*, and the end *B* then secured firmly by means of the screw *D*. The balance can then be put in adjustment by lowering the beam supports, so that the smallest possible strain is put on the fiber.

The results of tests on this machine are shown in the following table:

Fibers.	Breaking Strength, Grams.	Extension as Percent of Original Length.
Scoured Egyptian sliver	7.2	7.4
Ditto, mercerised without tension	6.7	12.2
Wool (merino top)	7.85	39.0
Silk	4.01	18.7
Artificial silk (viscose)	10.8	14.5
Linen fibers from aeroplane fabric	19.5	5.1
Bog cotton	4.7	2.4

(*a*) *Elasticity of Mercerised Cotton Fiber.*—In a particular experiment, a pull of 10.2 grams produced an elongation of 0.0552 cm. in a fiber of length 1.35 cm.; sectional area was approximately 0.000003 sq. cm.

$$\text{Elasticity} = \frac{\text{Stress per unit area}}{\text{Elongation per unit length}} = \frac{\frac{10.2 \times 981}{.000003}}{\frac{.0552}{1.35}}$$

$$= 0.8 \times 10^{11} \text{ c.g.s. units.}$$

Elasticity of quartz fiber is 5×10^{11} c.g.s. units and of cast iron about 12×10^{11}.

(*b*) *Tensile Strength of Cotton Fiber.*—A fiber of 0.000003 sq. cm. sectional area broke with a load of 7.2 grams.

$$\text{Tensile Strength} = \frac{7.2 \times 981}{0.000003} = 2.4 \times 10^{9} \text{ dynes per square centimeter.}$$

(Tensile strength of steel is 15×10^{9} dynes per square centimeter.)

14. Testing Tensile Strength of Yarns and Fabrics.—As the determination of the strength of individual fibers is a rather painstaking and tedious operation, it is more customary to test the breaking strength of yarns or fabrics. This is sometimes even better for commercial work than the testing of the single fibers, as it is really the strength of the manufactured yarn or cloth that is desired for most practical purposes. The strength and elasticity of yarns is readily obtained on special testing machines such as those shown in Figs. 206, 207, and 208. Cloth-testing machines are also constructed in much the same manner. Another method of determining the strength of cloth is to obtain the "bursting strain" by means of the well-known Mullen tester used so much for testing the strength of paper.

A yarn-testing apparatus that automatically records the strength and elasticity is shown in Figs. 209 and 210. It is known as the Zeidlitz apparatus and operates as follows: *A*, yarn to be tested as it comes off the cop and passes over two half-round pegs at *a* to take up slack. *B*, string passing over disk, *S*, and ends fastened to balance weights, *G* and *M*. *C*, fixture for fastening one end of yarn. *D*, a clamp attached to *M* for fastening the other end of the yarn. *E*, lever with pivot point or fulcrum between the ends. *F*, a small weight attached to string which passes over a pulley, around top of drum, *P*, over pulley and is attached to *H*. The weight of *F* is equal to the weight of *H* in water. *G*, weight attached to string, *B*, and equal to weight of *M* when empty. *H*, weight

floating in water, so that its weight floating is equal to *F*. *M*, a graduated glass flask, suspended by a cord, *B*, by an attachment at the top of *M*. To this attachment, clamp, *D*, is fastened, so that when *M* descends, *D* also goes down, putting tension on yarn. *N*, a vessel containing water, in which *H* is floating. To the top of *N*, a pulley is attached, acting as a guide for a string attached to *F*. *P*, drum which turns on a vertical axis by the pull of the string connecting *F* and *H*. Upon this drum is a clamp which will hold a piece of paper wrapped around the drum. This paper is divided into coordinates, vertical and horizontal lines at regular intervals. The horizontal lines indicate units and per-cent of stretch or elasticity; vertical lines indicate units of strength. As soon as the yarn breaks, *O* no longer stretches the yarn, *C* is not pulled down, *V* is closed, thus instantly shutting off the water going into *M*, and *W*, acting as a ratchet, engages the teeth stop, *S*. Thus the amount of water in *M* records the breaking strength of the yarn; *S* records the stretch of yarn; and the chart on *P* keeps a record of the stretch and strength of the yarn from zero to the breaking load.

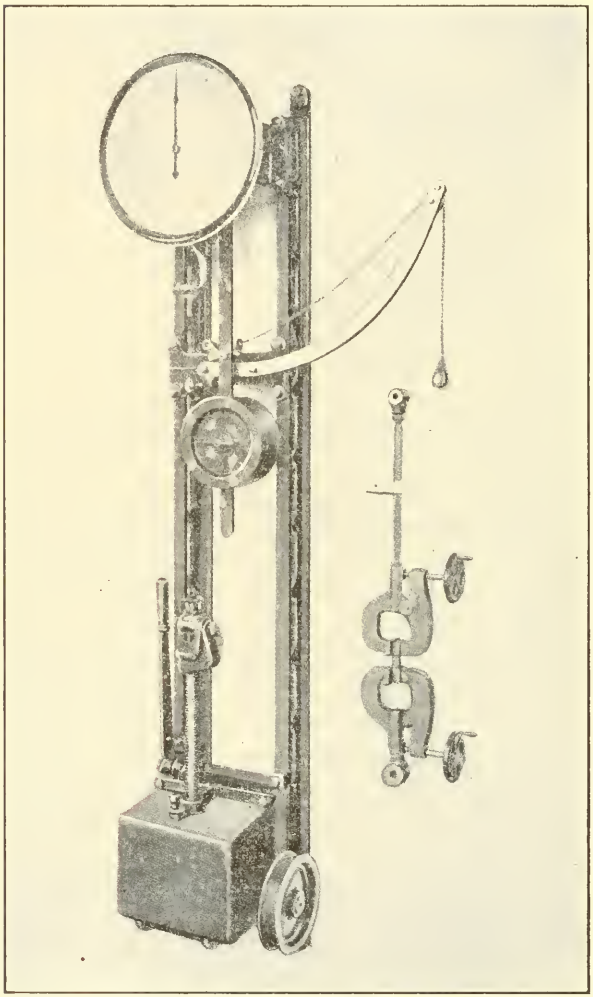


FIG. 206.—Combined Power Yarn and Cloth Tester. (Scott.)

In the testing of cotton goods for tensile strength, it is recognised that the only accurate way is to dry out all the moisture before the test.

The moisture plays a leading part in the strength of the goods, since one percent of moisture regain adds about $6\frac{1}{2}$ percent of strength to the goods. It is quite essential, therefore, that the breaking strength as shown by tests should be readjusted to the same moisture content. The following

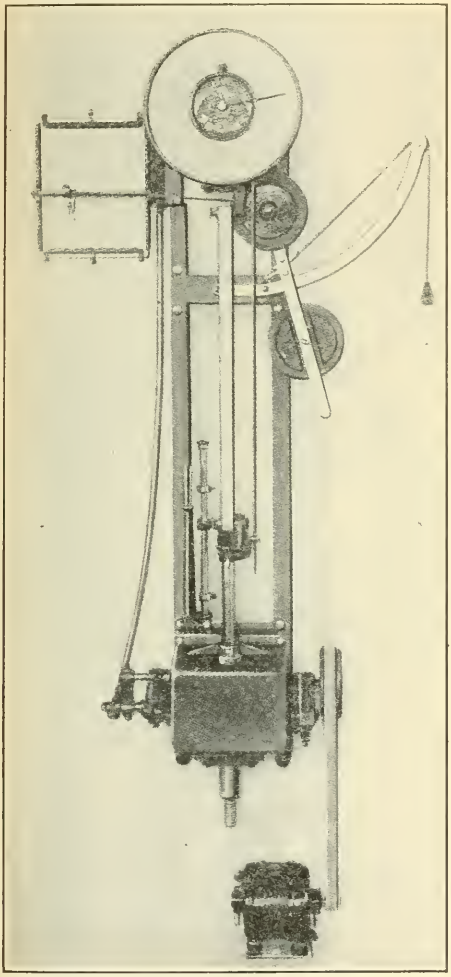


FIG. 207.

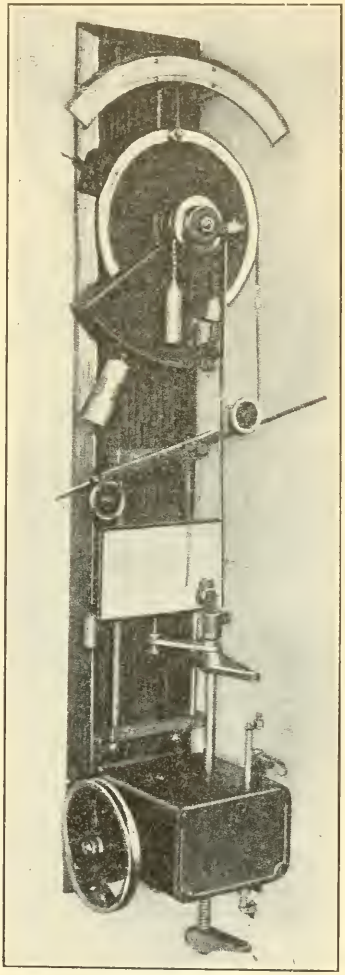


FIG. 208.

FIG. 207.—Skein Yarn Tester with Automatic Recorder. (Scott.)
FIG. 208.—Single Strand Yarn Tester.

formula recommended by the Textile Committee of the American Society of Testing Materials may be used in making the calculation:

$$\left.\begin{array}{l}\text{Tensile strength corrected to}\\ \text{6.5 percent moisture regain}\end{array}\right\} = \frac{\text{Machine reading} \times 139}{100 + (6 \times \text{actual regain})}$$

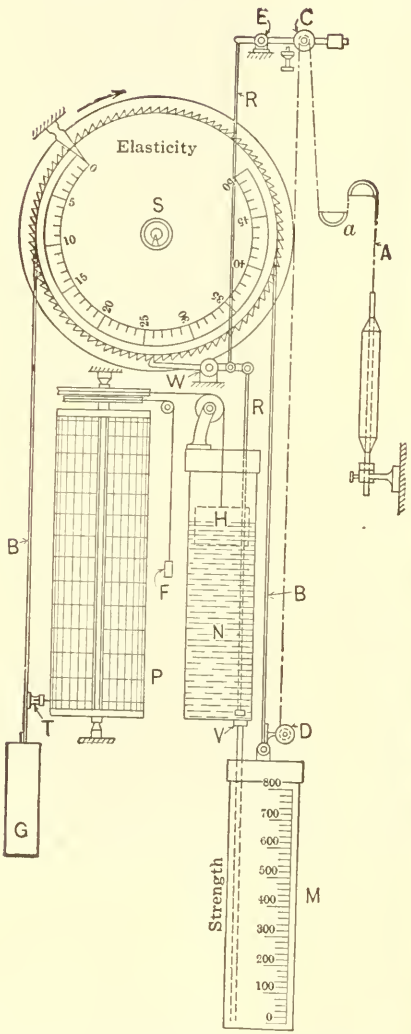


Fig. 209.—Diagram of Zeidlitz Tester.

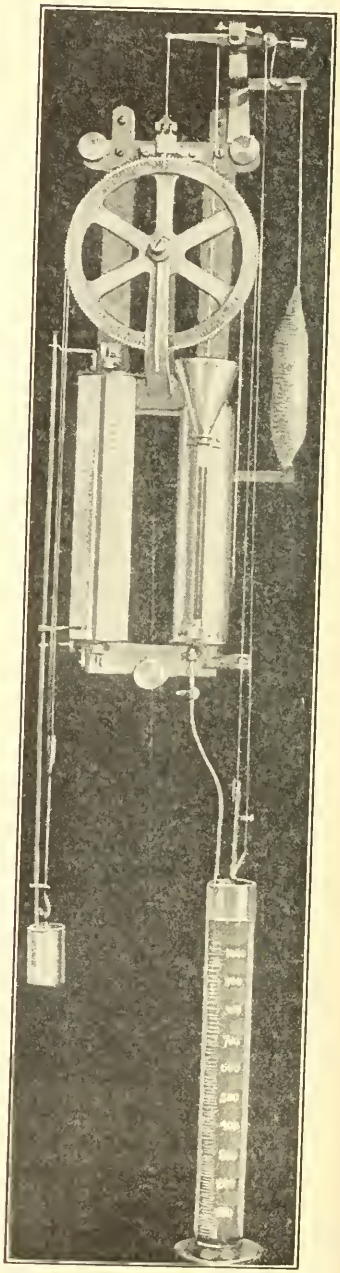


Fig. 210.—Yarn Tester. (Zeidlitz.)

Scheurer [1] made some interesting tests on cotton fabrics with regard to the effect of various treatments on the strength, the results of which are given in the following table:

	Relative Strength.
1. Bleached fabric (standard)	100
2. Hung for one month in aging room	98
3. Hung for one month in drying chamber	96
4. Hung for one month in wool-drier	96
5. Exposed for one month to air and rain	98
6. Passed twenty times through washer	96
7. Soaped six hours at 212° F. (2 grams soap per liter)	101
8. Soaped twelve hours as above	99
9. Passed ten times around calendering roll	80
10. Treated as (9) and washed	78
11. Damped and dried on cylinder twenty times	97
12. Boiled thirty minutes in soda ash (10 grams per liter)	100
13. Treated with 5 percent solution of chloride of lime of 10° Tw., dried on cylinder and treated as (12)	100
14. Treated as (13) twice	98

A form of tester especially designed for the testing of fabrics is that shown in Fig. 211. This apparatus gives the tensile strength of the material in pounds per linear inch, and is operated hydraulically. The cylinder is filled with a liquid which is compressed by a solid metal plunger, which fits the cylinder with a very accurately ground and lapped fit, and has no packings to wear out or get out of order. This plunger is attached to the upper or stationary clamp by means of a stirrup which brings the pull in a straight vertical line without cramping and without side pull. The lower or moving clamp is attached to a vertical screw which is operated by means of a handwheel on the side of the machine. The pressure is indicated on a specially made standard gauge which is acted on by hydraulic pressure from the cylinder. The readings are given in pounds per inch breaking strength of a strip of cloth or other material. The material to be tested is therefore cut into strips 1 in. wide. Removable and interchange-

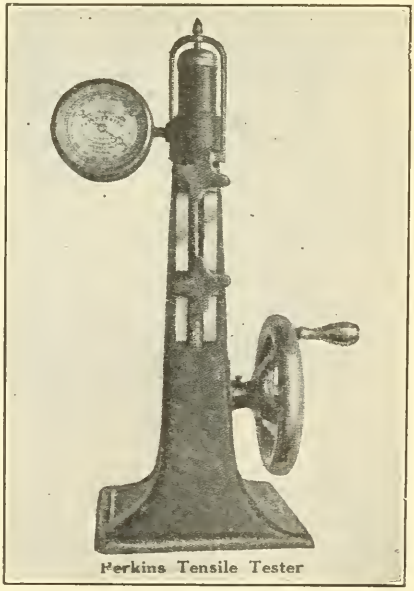


FIG. 211.—Perkins Tester for Strength of Fabrics.

[1] *Bull. Soc. Ind. Mlh.*, 1902.

able stop-gauges are provided which automatically separate the clamp jaws 1 in., 2 ins., or 4 ins. apart, as desired, so that strips of these lengths may be tested easily. The material is inserted and clamped uniformly and without side cramping by means of a device whereby the clamp jaws are held rigid during the insertion of the piece to be tested. As soon as the test is begun, the clamp jaws are freed so that they are on a swivel, and the strain of the material is thus taken up uniformly. When the hand-wheel has turned, the piece of cloth under test is subjected to a direct pull. This operates on the fluid in the cylinder, which simultaneously acts on

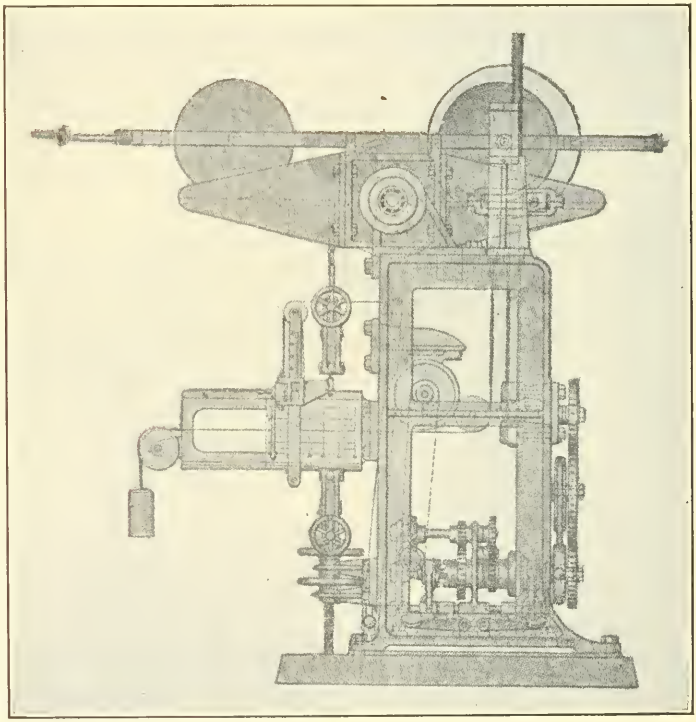


Fig. 212.—Testing Machine for Fabrics. (Scott.)

the standard pressure gauge. The pointer on the gauge stops automatically as soon as the material breaks, and thus accurately indicates the tensile strength of the material to the exact breaking point in pounds per inch, the pointer remaining stationary until it is released by pressing a button on the side of the gauge.

For determining the degree of uniformity of the tensile strength of yarns Lerch [1] recommends the following method: (1) Find the arithmetic

[1] *Monatschr. Text. Ind.*, 1922, p. 187.

mean of the results, the sub-mean and the super-mean; (2) determine the "quality" mean by adding the sub-mean and the super-mean and dividing by 2; (3) subtract the quality mean from the super-mean and multiply the remainder by the ratio of the greatest value to the lowest value and by 100. For example, if the super-mean is 280 and the sub-mean 220, the greatest value is 285 and the least value is 215, then the quality mean is 250, and the degree of uniformity is $(280-250)\times 100\times 285/215=15.6$ percent. If this value is less than 10 percent, the yarn may be considered as very even, and if above 20 percent as uneven.

In the Scott tester for textile fabrics an iron base supporting two side frames contains the entire mechanism, which is designed to be placed upon a bench or desk. Two bearings mounted upon the top of the side frames carry a walking beam or inclinable plane upon which rest two round weights connected together by a ball-bearing carriage. Fastened to a cross bar in this carriage is a chain which passes over a pulley and, dropping in a vertical direction, supports the upper or moving clamp. The lower clamp is attached rigidly to the frame but is mounted upon a screw and is adjustable for different lengths of specimens. The inclined plane is operated by sliding cross heads on either side, which in turn are lowered by means of a vertical screw upon which a worm gear acting as a nut revolves. The worm driving this gear is operated by a train of change gears driven from the mechanism below. These change gears permit of regulating the speed of the screw and in turn the inclination of the beam, and thus determine the rate of load applied to the specimen. The driving mechanism is operated by a belt from a small motor held within the main frames. Two clutches, independently operated, control the drive during the test and provide a quick speed return. Automatic stops make the machine automatic and prevent damage to the machine from neglect of the operator. When the specimen to be tested has been placed in the clamps the machine is started by means of a small lever at the front. The operator may stop the machine at the instant the break occurs; the strength test will then be registered upon a dial, and the stretch or elasticity upon the scale in front of the recorder. If desired, the machine may be allowed to operate automatically, the graph developed by the recording instrument giving both strength and stretch records. The chart is square ruled and evenly spaced, the vertical lines denoting strength and the horizontal lines the stretch. As the test progresses the chart moves horizontally from right to left while the pen, supported from the rider on the scale, moves upward as the specimen elongates. These two movements produce a diagonal line upon the chart showing the exact progress of the test from the start to the break. One special feature of this recorder is the fact that its operation in no way interposes friction to be overcome by pull on the specimen or in any way influences the test.

15. Hygroscopic Quality.—Cotton is less hygroscopic than either wool or silk; under normal conditions it will contain from 5 to 8 percent of hygroscopic moisture, though in a very moist atmosphere this may be considerably increased.

Kuhn [1] states that a portion of this moisture must be regarded as a constituent part of the fiber. This water of constitution, he states, amounts to about 2 percent. It can be expelled at over 105° C., and the fiber then becomes harsh and brittle, and loses its elasticity. This statement concerning water of constitution, however, demands further investigation before it can be unreservedly accepted as a fact.

The following table shows the results of a series of tests to determine the hygroscopic moisture in various grades of cotton:

Grade.		Percent of Moisture.		
		Maximum.	Minimum.	Average.
North American..	Texas	14.8	6.9	9.2
	Orleans	9.9	7.8	9.7
	Memphis	9.8	7.1	9.4
	Sea-island	9.9	7.4	9.6
	Savannah	16.2	10.7	13.8
	Norfolk	10.3	8.4	9.4
	Florida	8.9	7.2	8.7
South American..	Maceio	8.1	....	8.1
	Paraiba	8.3	....	8.3
	Brazil	11.8	7.3	9.5
	Peru	9.8	7.5	9.1
Egyptian	Ashmouni	9.5	6.8	8.4
	Gallini	10.8	7.1	9.3
	Brown	8.7	7.8	8.5
Indian	Surat	7.7	6.2	7.5
	Dhollerah	8.1	6.4	7.0
	Bengal	8.2	....	8.2
	Tinnevelly	7.9	....	7.9

Beltzer [2] states that Indian cottons under the same atmospheric conditions absorb about 1.5 percent more of moisture than American cottons, though this difference is only manifested within certain limits as to the saturation of the air with water vapor; when the relative humidity is 50 percent the difference in the amount absorbed is only 1 percent. Egyp-

[1] *Die Baumwolle*, p. 131.

[2] *Les Matières Cellulosiques.*

tian cotton is said to occupy an intermediate position between Indian and American cottons. In the absence of definite data in this respect, however, the present author is inclined to question the conclusions of Beltzer.

The hygroscopic quality of cotton (and, in fact, of any other vegetable fiber as well) has much to do with its proper condition during the various processes of spinning and finishing. It also has an influence on the commercial valuation of the raw material, as the amount of hygroscopic moisture varies with atmospheric conditions, and it is important to have a normal standard of reference. Its influence on spinning is even greater, and proper conditions of atmospheric moisture must be maintained in the spinning-room in order to achieve the best results. The spinning properties of raw cotton, however, are also affected by other substances associated with the cellulose of the fiber, but it is without question that the physical condition of cotton is largely influenced by its content of hygroscopic moisture, and this should be delicately adjusted by the spinner to meet the conditions of his work. The mechanical treatment of woven textile materials in finishing processes, such as mangling, beetling, calendering, etc., is also dependent for good results to quite an extent on the hygroscopic condition of the fiber, hence the amount of moisture present during the finishing operations, together with the method and degree of drying, should be carefully studied.

In testing the influence of moisture on the strength of cotton material, the Industrial Society of Mulhouse reports as follows:

Normal strength of cloth	100
Saturated with moisture	104
Dried on hot cylinder	86
Again dampened	103

It would appear from these results that the alternate moistening and hot drying of cotton caused little or no deterioration in its strength.

L. Pinagel has shown that bleached cotton on the average will absorb somewhat less hygroscopic moisture than unbleached cotton. Yarn spun from different grades of cotton in the bleached and the unbleached condition were dried in a conditioning apparatus and the dry weight noted. These yarns were then hung in the same room and the weight of each skein at the end of sixty hours was also noted. It was found in almost every case that the bleached yarn took up less moisture than the unbleached. Too much confidence, however, must not be placed in these results, as the difference between the bleached and unbleached cotton was quite small and was often less than the differences between the different kinds of cotton used.

The amount of " regain " allowed in the conditioning of cotton on the continent of Europe is $8\frac{1}{2}$ percent. The following table by Hartshorne gives the " regain " of cotton for various temperatures and humidities:

TABLE OF REGAIN FOR COTTON AT VARIOUS TEMPERATURES AND PERCENTAGES OF HUMIDITY

Percentage Humidity.	Degrees Fahrenheit.					
	50	60	70	80	90	100
40	5.90	5.79	5.65	5.47	5.25	5.05
50	6.89	6.78	6.63	6.45	6.18	5.86
60	8.00	7.87	7.69	7.44	7.13	6.80
70	9.14	9.00	8.79	8.58	8.32	8.05
80	10.58	10.42	10.23	9.95	9.70	9.60
90	12.28	12.10	11.85	11.56	11.43	11.85
100	14.12	14.00	13.80	13.65	13.70	14.50

The temperature and percentage of humidity suitable for various departments of a cotton mill vary with the nature of the process and the fineness of the yarn. The finer the yarn the higher should be the humidity. The following table represents the general practice:

	Humidity, Percent.	Temperature, Degrees F.
Card-room	60–65	70–75
Spinning-room	60–75	75–80
Weaving shed	75–80	70–75

Thomson has pointed out the effect of moisture on the strength of cotton yarn in finishing. He gives the following figures:

Moisture in Yarn, Percent.	Breaking Strain.
2.89 (dry)	39.9
8.93 (usual)	64.0
17.36 (moist)	69.2

Other investigators have substantiated these results. The increase in elasticity of moist yarn over dry yarn is about 25 percent, while the increase in strength is about 10 percent.

Cotton may combine with water in two forms: (1) as hydroscopic moisture and (2) as water of hydration. The hygroscopic moisture is that absorbed from moist air, and varies in quantity from 8 to 12 percent, depending on the temperature and humidity of the air. This water is completely eliminated by heating the cotton to 220° F., and the cotton may then be termed "desiccated." The water of hydration is only

separated at a higher temperature, 320° to 350° F. being necessary. At these temperatures a further loss in weight of 1 to 3 percent is obtained. The water of hydration may also be estimated by first desiccating the cellulose at 220° F., then boiling in toluene and distilling. Cotton containing water of hydration is known as cellulose hydrate or hydracellulose. The limit of the hydration in cotton may be considered as corresponding to mercerised cotton, $C_{12}H_{20}O_{10}\cdot H_2O$ (see Cellulose Hydrate). These statements, however, need further experimental data to confirm their accuracy.

When cotton is purified from its adhering waxy and fatty matters, it becomes remarkable **absorbent.** This quality is explained on the supposition that the ripe cotton fiber is made up of a series of tissues of cellulose, separated from each other by intercellar matter, in this way forming a series of capillary surfaces which are capable of exerting considerable capillary force upon any liquid in which the fiber may be immersed. Dry cotton also appears to be remarkably absorptive of gases; it is said that the fiber can absorb 115 times its volume of ammonia at the ordinary atmospheric pressure.

When properly prepared, absorbent cotton should absorb 18 times its own weight of water.[1] On account of the great absorbency of purified cotton it is very extensively used in the preparation of surgical cotton and gauze for the packing of wounds and other uses in medical practice and surgery. For this purpose the cotton must be very thoroughly boiled out and bleached and subsequently medicated if so desired.

The following accurate method of determining the amount of hygroscopic water in cotton (or other cellulose fiber) has been suggested by C. Schwalbe. About 3 grams of the material is boiled with 300–500 cc. of pure toluene which has a boiling-point of about 230° F. The water is collected by distillation in a graduated tube and from a determination of its volume or by weighing, the percentage of moisture may be calculated. This method is applicable to the determination of moisture in mercerised cotton and hydrated celluloses (artificial silk). The following gives the amount of moisture as determined in this manner with different materials:

	Percent.
Paper made from cotton	6.5
Vegetable silk	6.7
Mercerised cotton	9.25
" wood pulp	10.25
Viscose silk	11.25

[1] The cotton stock employed for making absorbent cotton and surgical gauze is obtained from linters, card strips, card fly, and comber waste, the last-named giving the best grades. Mill sweepings cannot be used for making surgical cotton as they cannot be bleached to a satisfactory white color. The mill sweepings are generally employed for the making of guncotton and low-quality wadding for clothing.

Cotton which has been deprived of its hygroscopic moisture by drying in an oven at 212° to 220° F. by the usual method, easily regains its original amount of moisture after ten to twelve hours' exposure to the air. When the moisture has been removed by boiling toluene, however, the regain in moisture is somewhat less, on account of the impregnation of the fibers. The method of washing cotton with alcohol before drying is objectionable, owing to the fact that cellulose obstinately retains alcohol which apparently cannot be removed by heat. When the drying operation is conducted at too high a temperature the regain of moisture is also less, so that the normal region of moisture may be taken as the exact measure of the hygroscopic moisture, without the elimination of the water of hydration. Schwalbe found that the toluene method only eliminated the hygroscopic moisture present and did not affect the " water of hydration."

The difference in the amounts of hygroscopic moisture absorbed by cotton subjected to various treatments is given by Higgins[1] as follows:

	Percent.
Ordinary cotton, unbleached	6.52
" " bleached	6.25
Mercerised without tension, unbleached	9.33
" " " bleached	9.12
" with tension, unbleached	8.28
" " " bleached	8.05

The moisture content was determined after exposure to the air for one week. It is interesting to note that bleached cotton absorbs less moisture than unbleached cotton in all cases. This is probably due to the fact that the pectin and gums on the fiber take up a greater proportion of water than pure cellulose itself. In another set of experiments Higgins gives the different amounts of moisture absorbed by cotton mercerised under various conditions, as follows:

	Percent.
Ordinary cotton	6.20
Mercerised with caustic soda at 10° Tw	6.37
" " " 20° Tw	6.68
" " " 30° Tw	8.40
" " " 40° Tw	9.41
" " " 50° Tw	9.43
" " " 60° Tw	9.57
" " " 70° Tw	9.69

Higgins also showed that cotton cloth which has thoroughly dried will not absorb the amount of moisture it originally contained in the air-dry state, even after long exposure to the atmosphere.

16. Lustering of Cotton Materials.—In order to increase the value and appearance of cotton fabrics, many attempts have been made to

[1] *Jour. Soc. Chem. Ind.*, 1909, p. 188

give cotton a high luster. This lustering may be done either by mechanical or by chemical means. In the latter case where a chemical change is brought about within the fiber, the processes are usually dealt with under the subject of mercerising. There are also other chemical processes in which the fiber is coated with a substance having a high index of refraction. There is also the more modern method in which the surface-cellulose of the fabric is converted into nitrocellulose or acetylcellulose. According to *U. S. Pat.* 954,310 the cellulose is converted into acetylcellulose by being treated with a mixture of anhydrous acetic acid and a small amount ($\frac{1}{2}$ percent) of sulfuric acid. The result is that the fabric is waterproofed and lustered at the same time. Some older patents protect the formation of a lustrous coating by means of a varnish of waste silk dissolved in alkalies or cuprate of ammonia. The goods to be lustered were soaked with the silk lye, and then the silk was fixed from solution by treatment with a mineral acid, carbonic acid, or a bicarbonate (*Ger. Pat.* 64,457 and 98,968).

In other methods the silk lye is replaced by solutions of collodion or of nitrocellulose in alkalis. In a process protected by *Ger. Pat.* 24,795, the outer part of the fiber is converted into nitrosaccharose. The worst of these methods is that they do not pay. Hence, barring mercerisation, they have been abandoned in favor of mechanical methods. The oldest of these are pressing and calendering, and the first great improvement on these processes was the invention by Robert Deissler (*Ger. Pat.* 85,368 of 1894) of engraved calender rolls. The finish produced by their use has found much favor under the name of Schreiner finish, or silk finish. A later improvement consists in using ribbed rolls set at an angle to each other. This arrangement gives a better luster with blunter edges on the cylinder grooves. The action depends on friction at an angle to the length of the warp. Various modifications of this system were made with the idea of getting a luster which, in addition to being very considerable, should also be fast to water and ironing. In Sharp's English patents, the goods are covered with a uniformly damped or steamed linen blanket and then pressed or calendered under high pressure. In Depierre's method for finishing cotton fabrics, the goods are calendered while still damp under heavy pressure with hot smooth metal rollers, which dry and luster them at the same time. The greasy luster thus obtained is often covered by putting the fabrics through a ribbed calender afterward. In the patent of Carl Rumpf, of Elberfeld (*Ger. Pat.* 220,349), strong heating of the goods is mentioned as a means of fixing the luster fast to water and ironing, greasy lustered goods being run in a state of tension between hot rollers or passed in a state of tension between hot rollers or passed over gas flames. They are then given a soap-and-water bath whereby the greasy luster is removed and the silky luster which has been superadded remains alone.

In a later patent the heating is made to produce as well as fix the luster, but then temperatures above 400° C. are necessary.

Another method of producing luster fast to water and ironing is the subject of *Ger. Pat.* 88,946 of 1896. The fabric is soaked with a solution of albumen, goffered and dried. The drying coagulates the albumen and fixes the goffering. This process was found to labor under the practical difficulty that the albumen made the goods stick to the goffering calenders. This was partly remedied by the invention specified in *Ger. Pat.* 206,901 (F. During), according to which the calendering is done with rollers which are heated, but not sufficiently to coagulate the albumen. This was done by further heating after the goods had left the calender. At the same time, the luster got by goffering with a calender not very hot was inferior, and the tendency of the goods to stick was still considerable, especially with finely engraved cylinders. Hence, in the additional patent (*Ger. Pat.* 217,679), the goods were dried after having been albumenised, but while still uncalendered, at a temperature insufficient to coagulate the albumen. The coagulation was then effected by hot calendering, reinforced by steaming or by treatment with formaldehyde. To prevent too much stiffness, oil may be added to the albumen solution, which may also be applied on one side only of the goods.

We now come to processes in which the lustered surface is covered and protected by an independent insoluble waterproof coating. According to Eck's method (*Ger. Pat.* 232,568), an acid solution of gelatine-formaldehyde is applied by means of rollers, and coagulated on the fabric without heat by means of the fumes of ammonia. It had before been proposed to coat the surface of the goods with collodion by spraying them with the solution of nitrocellulose in a mixture of ether and alcohol. The film thus produced on the fabric is opalescent owing to the presence of water, and is distinctly visible. This was prevented by the processes described in *Ger. Pat.* 212,695 and 212,696, which make the collodion solution not with the usual mixture of ether and alcohol, but with amyl acetate or amyl formate, which gave liquids which contain 1 to 2 percent of nitrocellulose and can be dyed with any dye soluble in the amyl salt. Bernhard Zittau (*Ger. Pat.* 233,574) uses a solution of india rubber or guttapercha, together with paraffin-wax or ceresine in some sort of hydrocarbon, preferably benzene.

On reviewing these attempts to make a mechanically produced luster fast to water and ironing, we note that the result is produced either by powerful heating of the goods, or by covering their fiber with an insoluble coating. Complete fastness to ironing and damp cannot be attained by mere heat unless the temperature is so high as grievously to endanger the fiber.

CHAPTER XV

CONSTITUENTS OF RAW COTTON

1. Chemical Constitution.—In its chemical composition cotton, in common with the other vegetable fibers, consists essentially of **cellulose.** On the surface there is a protecting layer of **wax** and **oily matter** and also in the fiber there is a trace of **pigment** which in some varieties of cotton becomes quite emphasised. The removal of these substances is the object of the boiling-out and bleaching process to which cotton is subjected prior to its dyeing and printing. In reality the purified cotton fiber as it exists in bleached material is practically pure cellulose, and this compound alone appears to be essential to its structural organisation.

The cellulose of cotton is of very constant composition and easy to purify. It is termed *normal cellulose* to distinguish it from other types of cellulose present in many other vegetable fibers where the cellulose is in combination with pectin (linen type) and lignin (jute type).

2. Impurities in Cotton.—The natural impurities present in the raw cotton fiber amount to about 4 to 5 percent, and consist chiefly of pectic acid, coloring matter, cotton-wax, cotton-oil, and albuminous matter. The fiber gives about 1 percent of ash on ignition. Bowman is of the opinion that considerable stress should be laid on the fact that the cotton fiber contains about 1 percent of mineral matter as an integral part of its constitution, and this no doubt has considerable influence on its structure and properties. It is usually stated that cotton yarn loses from 5 to 7 percent of its weight during purification by bleaching, the figure for cloth being larger by the amount of material added during sizing. Jecusco,[1] for example, states that American cotton yarn on boiling with 3 percent caustic soda and 2 percent sulfated oil at 15 lbs. for eight hours loses 6.45 percent, the loss increasing to 7.3 percent on full bleaching. Using soda ash instead of caustic soda and following with a stronger hypochlorite solution, the loss in weight was 7.1 percent. Trotman and Pentecost[2] point out the necessity of considering the moisture present before and after bleaching in working out figures of this kind. In a number of carefully

[1] *Jour. Soc. Dyers & Col.*, 1917, p. 34.
[2] *Jour. Soc. Chem. Ind.*, 1910, pp. 4–6.

conducted laboratory experiments, the following figures were obtained for the loss during the soda boil:

Reputed Count.	Loss Percent.	Number of Tests.
24/2 American.....	5.30	7
32/2 "	4.01	36
40/2 "	4.35	15
70/2 "	3.90	29
70/2 Egyptian.....	6.54	8
80/2 "	4.59	12
100/2 "	4.35	18
120/2 "	4.60	12
150/2 "	4.55	6

The comparative effect of a number of reagents on the same cotton under standard conditions were found by Trotman and Pentecost to be as follows:

Reagent.	Loss Percent.
Potassium hydroxide.....	5.00
Sodium hydroxide.....	4.40
Sodium carbonate.....	3.70
Sodium borate.....	2.80
Sodium silicate.....	2.40

The **oil** present in the fiber appears to be identical with cottonseed-oil, and is probably obtained from the seed to which the fiber is attached.

The **cotton-wax** serves as a protective coating for the fiber and makes it water-repellent, as is evidenced by the long time required by raw cotton to become wetted-out by simply steeping in water. This wax appears to be closely analogous to carnauba wax; it is not soluble in alkalies, though it may be gradually emulsified by a long-continued boiling in alkaline solutions, on which fact is based the " boiling-out " of cotton by the ordinary methods. Cotton-wax, however, appears to be readily soluble in sulfated oils, such as Turkey-red oil, and hence cotton may be rapidly and thoroughly wetted-out by using a solution of such an oil. The coating of wax over the cotton fiber appears to influence its spinning qualities to a certain extent, as it requires, for instance, a rather elevated temperature to successfully spin fine yarns, in order probably to soften the waxy coating of the fiber. As the temperature falls the oily wax tends to become stiff and gummy and prevents the proper drawing of the fiber in spinning. Its presence among the thin laminations of the cell-walls gives a greater

elasticity to the fiber, and renders it less liable to sudden rupture. The gradual drying up of the more volatile portions of this oil in the fiber, leaving the remaining portion thicker and stiffer, may also, and probably does, account for the fact, noticed by most spinners, that new crop cotton seems to work better and makes less waste than cotton harvested as the season advances.[1] Spinning trials of Egyptian cotton deprived of its wax [2] showed that the material behaves very badly in the drawing and spinning processes, giving an excessive amount of waste, irregular results, and showing a tendency to adhere to the rollers. Finer counts give great trouble, and breakages are extremely frequent. In the loom, as warp, it is equally troublesome. Extraction with benzene after spinning, however, increases the strength, but diminishes the elongation of the yarn as shown in the following table:

	American, Percent.	Egyptian, Percent.
Increase in strength	12.4	11.0
Decrease in elongation	4.0	9.9
Average counts Before	56.8	58.1
Average counts After	58.2	58.9

The addition of 2 percent of paraffin wax to the extracted yarn decreases its tensile strength by 33 percent. Yarn spun from extracted cotton is from 24.5 to 27 percent weaker than that from normal cotton.

The fatty acid present in cotton-wax has been found to be identical with margaric acid. According to Dr. Schunck, American cotton contains about 0.84 percent of fatty matters, whereas East Indian cotton contains only 0.337 percent.

Analysis of cotton-wax shows it to consist of the following:

	Percent.
Carbon	80.38
Hydrogen	14.51
Oxygen	5.11

It fuses at 85.9° C., and solidifies at 82° C., hence it bears a close analogy to both cerosin, or sugar-cane wax, and carnauba wax.

Cotton-gum or wood-gum is the name given to the product extracted from cotton by boiling alkali and not precipitated by alcohol. It is not equivalent to cotton-wax, as it contains not only the latter but also the pectic and fatty matters of the fiber.

The effect on the cotton-wax on various finishing operations in the

[1] Bowman, *Cotton Fiber*, p. 55.

[2] *Jour. Text. Inst.*, 1911, p. 22.

manufacture of cotton fabrics is found to be of considerable importance. It is almost impossible to obtain the effect of the bettle finish if wax is left in the cotton. Even the trace of wax left after scouring and bleaching may be sufficient to create this difficulty, and the use of unsaponifiable material in sizing the warp yarn would of course aggravate the trouble. For this reason, extraction with suitable solvents is strongly recommended by Fort[1] and a process has been patented which can be applied before or after bleaching, or after dyeing, and even while the fabric is wet.[2]

To show the effect of various operations on the wetting-out of cotton Beadle and Stevens[3] pressed various samples of air-dried cotton into loose wads, 15×10 mm., weighing 0.1 gram each, and let them fall from a certain height on to the surface of a column of water. The time taken to pass through the surface was used as a measure of the " wetting " property of cotton. The following results were obtained:

Cotton, raw	More than 24 hours
Cotton, bleached but not scoured	31.3 seconds
Cotton, boiled in 1.0 percent NaOH	12.3 "
Cotton, boiled in 2.0 percent NaOH	5.7 "
Cotton, boiled, bleached and boiled again	4.0 "
Cotton, extracted with ether and alcohol	0.5 "

The removal of the wax is one of the principal objects of the lime and soda boils, and their relative efficiency has been largely debated. It appears to be generally conceded that, as a single operation, the soda boil has the greater effect, as indicated, for example, by the following table of Trotman and Thorp,[4] the figures being the percentages of ash, etc., left in the fiber:

	Experiment I.		Experiment II.		Experiment III.	
	Soda Boil.	Lime Boil.	Soda Boil.	Lime Boil.	Soda Boil.	Lime Boil.
Ash	0.26	0.52	0.26	0.50	0.42	0.56
Free fat	0.10	0.26	0.20	0.15	0.16	0.11
Fatty acids (as soap)	0.16	0.22	0.13	0.21	0.26	0.56
Nitrogen	0.05	0.07	....	....	0.07	0.07

[1] *Jour. Soc. Dyers & Col.*, 1921, p. 161.
[2] Lumsden, Mackenzie and Fort, *Brit. Pat.* 137,968.
[3] *Jour. Soc. Chem. Ind.*, 1913, p. 174.
[4] *Bleaching and Finishing of Cotton Goods*, p. 95.

It is when the lime boil is considered in relation to the lime-sour-soda-sour sequence that opinions differ. Both Higgins [1] and Trotman and Pentecost [2] agree that in the lime boil and saponified portion of the wax is hydrolysed and that the subsequent souring converts the insoluble soaps left on the fiber into free acids, which remain in close contact with the unsaponifiable matter, so that in the lye boil a soap is produced and rapid emulsification and elimination of the unsaponifiable matter result. The latter authors consider, however, that this result is achieved equally well by the direct soda boil.

Knecht and Allan [3] found that the benzene extract of raw cotton could be differentiated by means of petroleum ether into "soluble cotton wax A" and "insoluble cotton wax B." For the Egyptian cotton on which the main investigation was conducted the ratio was 72 percent of the soluble wax to 28 percent of the insoluble, while for an American cotton it was 80 to 20 percent. *Cotton Wax A* is odorless, dull yellow in color and closely resembles beeswax in texture and fracture. It has a melting point of 150° to 154° F.; iodine value 28.55; acid number 44.1 and saponification value 84.3. About 18.8 percent is undissolved by boiling 96 percent alcohol. It is saponified with difficulty, but by using glycerol and sodium hydroxide it gives 47.5 percent of unsaponifiable matter, consisting of (*a*) hydrocarbons (hentriacontane ($C_{31}H_{64}$) and dotriacontane ($C_{32}H_{66}$) were definitely isolated); (*b*) a phytosterol, giving an acetyl derivative melting at 257° F., but otherwise unidentified; and (*c*) fatty alcohols unidentified owing to lack of material. The soap yields palmitic, stearic, and cerotic acids. *Cotton Wax B* forms a dark green granular mass, with a melting point of 154° F., acid number 4.03 and saponification number 83.3. The unsaponifiable portion yields 33.5 percent of a reddish brown, sticky wax melting at 145° F., and giving on acetylation a considerable quantity of a phytosterol acetate with a melting point of 253° F. The soap yields a small proportion of melissic acid.

In a very exhaustive investigation on the extractive constituents of American cotton, Fargher and Probert [4] by extraction with benzene showed that the principal constituent is a new alcohol, to which they gave the name gossypyl alcohol, with the formula $C_{30}H_{62}O$. The different substances found in the various parts of the crude extract are shown in the following table, the substances present in relatively large amounts being given in black-face type and those present in only very small amounts in italics:

[1] *Bleaching*, p. 40.
[2] *Jour. Soc. Chem. Ind.*, 1910, pp. 4–6.
[3] *Jour. Soc. Dyers & Col.*, 1911, p. 142.
[4] *Jour. Text. Inst.*, 1923, p. 49.

CRUDE BENZENE EXTRACT OF RAW AMERICAN COTTON

A. Soluble in light petroleum—
  1. Sparingly soluble—
    gamma-**Gossypyl alcohol**
    beta-Gossypyl alcohol.
  2. Readily soluble—
    Free acids: palmitic, stearic and *oleic.*
    Acids as esters: **carnaübic,** palmitic, stearic and oleic.
    Montanyl alcohol, gossypyl alcohol.
    Solid hydrocarbons: triacontane, hentriacontane.
    Liquid hydrocarbons; b.p. 170°–220° C. and b.p. 150°–210° C.
    Phytosterol, principally sitosterol.
    Amyrin.

B. Soluble in ether—
  1. Sparingly soluble—
    Montanyl alcohol.
    Sitosterolin.
    Palmitic acid.
    Stearic acid.
  3. Readily soluble.
    Montanyl alcohol.
    Palmitic acid.
    Stearic acid.

C. Soluble in benzene—
  1. Sparingly soluble—
    beta-**Gossypyl alcohol.**
  2. Readily soluble—
    beta-*Gossypyl alcohol, palmitic acid, stearic acid.*

D. Soluble in alcohol—
  1. Sparingly soluble—
    beta-Gossypyl alcohol, *ceryl alcohol.*
    Sodium salts of montanic, cerotic, palmitic and stearic acids.
  2. Readily soluble—
    Sodium salts of fatty acids.

E. Soluble in chloroform—
    alpha-Gossypyl alcohol, *carnaübyl alcohol.*
    an acid, $C_{34}H_{68}O_2$.

In obtaining the crude benzene extract it was found that after eight hours' extraction in a Soxhlet apparatus the extract amounted to 0.47 percent calculated on the air-dry cotton or 0.51 percent calculated on the bone-dry cotton. The extract consisted of a dark brown, plastic mass with the following characteristics:

Melting point	70° to 75° C.
Density	0.989
Acid value	30.6
Saponification value	65.0
Saponification value after acetylation	144.0
Acetyl value	83.0
Iodine value	21.0
Unsaponifiable matter	51 percent

Both Knecht and Piest [1] have ascribed reducing properties to cotton wax, as it appears to increase the "copper number" of cotton. The reducing agent may be similar to an aldehyde detected by Hoffmeister [2] in the wax of flax.

Hebden [3] indicates that the removal of fats and waxes soluble in ether during the soda boil takes places as follows:

Steep.	First Boil.	Second Boil.	Chemic.	Sour.
Percent.	Percent.	Percent.	Percent.	Percent.
5.5	20.4	64.0	67.8	69.6

Trotman and Pentecost [4] give the following typical analyses to indicate the difference between good and bad soda boils of cotton goods:

	After Good Boil, Percent.	After Bad Boil, Percent.
Mineral matter	0.05–0.75	1.00
Free fat	0.01–0.15	0.35–0.70
Fat as soap	Trace	0.25–0.50
Nitrogen	0.50–0.10	0.25–0.35

They emphasise the utility of sodium carbonate and of borax as emulsifying agents, but consider that the scouring effect of sodium silicate is offset by possible mechanical damage due to the deposit of silica on the fiber. Other suggestions for the more effective removal of waxes include the use of (*a*) a soap solution containing benzene,[5] (*b*) a mixture of potash soap, carbon bisulfide and olein,[6] (*c*) resin soaps, (*d*) benzene and other solvents brought into emulsion with Turkey-red oil, and (*e*) Turkey-red oil and oleic acid.[7]

Scheurer [8] studied the saponification of tallow, cottonseed oil, and the fatty constituents of raw cotton in contact with cotton cloth, and came to the following conclusions: (1) Sodium hydroxide is twice as effective as sodium carbonate in equivalent concentration; increasing the concentration of alkali from 5 to 10 parts per 1000 is without sensible effect; (2) mixtures of sodium hydroxide and sodium carbonate show maximum efficiency when the proportion of carbonate is equivalent to 25 percent of the total alkali, an effect which is ascribed to the mechanical properties of the

[1] *Zeitsch. angew. Chem.*, 1912, p. 396.
[2] *Ber.*, 1903, p. 1057.
[3] *Jour. Ind. Eng. Chem.*, 1914, p. 714.
[4] *Jour. Soc. Chem. Ind.*, 1910, pp. 4–6.
[5] *Chem. & Met. Eng.*, 1916, p. 160.
[6] Dyson, *Brit. Pat.* 10,311, 1913.
[7] *Bull. Soc. Ind. Mulh.*, 1903, p. 288.
[8] *Bull. Soc. Ind. Mulh.*, 1888, p. 399.

solution; (3) the addition of rosin increases the velocity of saponification, which is still further enhanced by increasing the concentration of the alkali; (4) the saponification of cotton-seed oil in contact with the fabric is relatively rapid, and appears to increase the rate of saponification of the natural fatty constituents of the raw cotton; (5) neutral fats (triglycerides) are much more rapidly attacked by alkaline solutions when mixed with readily saponifiable oils, owing probably to emulsification; (6) while the rapidity of the action of lime is noteworthy, the complete removal of the fatty matter can only be effected by a subsequent acidification and boiling with sodium carbonate; (7) the general statement is made that complete saponification of the fatty constituents of cotton may be effected (*a*) by a single treatment with sodium hydroxide and rosin, or (*b*) by the lime "sour soda ash" sequence, the latter process having the greater elasticity and certainty.

Knecht[1] considers it improbable that cotton wax is saponified under normal bleaching conditions, the wax being only partially removed, and then by emulsification. He quotes the following figures in support of the statement:

Scouring Agent.	Time.	Wax Removed, Percent.
Soda ash, 4° Tw.	4 hours	30
Sodium hydroxide, 2° Tw.	4 hours	28
NaOH, 2° Tw.+Castile soap (5 percent of weight of cotton)	25 minutes	45
NaOH, 2° Tw.+Castile soap (5 percent of weight of cotton)	4 hours	64
NaOH, 2° Tw.+resin soap (5 percent of weight of cotton)	25 minutes	73

Although the use of resin soap appears to be so effective, it has been suggested that if the water used contains lime or magnesia, resinates may be precipitated on the fiber and eventually produce a brown color.[2] The efficiency of potassium hydroxide compared with sodium hydroxide[3] and of strontia in relation to lime[4] has been considered. Potassium hydroxide is said to remove 20 percent more wax when used in equimolecular proportion for the same time, while strontia is supposed to exert a saponifying action three times as great as that of lime and to give a superior general bleaching effect. There is, however, the possibility of tendering, due to oxidation.

[1] *Jour. Soc. Dyers & Col.*, 1911, p. 142.
[2] *Jour. Soc. Chem. Ind.*, 1905, p. 267.
[3] *Jour. Soc. Chem. Ind.*, 1910, pp. 4–6.
[4] *Bull. Soc. Ind. Mulh.*, 1914, p. 499.

The retarding effect of neutral salts and of hard water on the soda boil is considered by Trotman in a later communication.[1] The same writer points out that wax retained after boiling may protect the cotton from the action of the "chemic," while Graf[2] considers that the reducing agents present in the wax cause the "bleeding" of vat colors in the lye boil, and indicates methods of overcoming this. Kollman[3] has studied the fall in reducing power of raw cotton in the course of the bleaching process; the greatest change taking place after the lye boil, when the majority of the secondary constituents are removed. Whether the yellowing of goods in storage is due in some measure to the wax appears to be undecided, Levine,[4] Crowther,[5] and Higgins[6] favoring the assumption, whereas Erban,[7] Hebden and Freiberger[8] are of the contrary opinion.

In bleaching, cotton from which the wax has been previously removed yields a "white" much superior to the untreated cotton.[9]

3. Chemical Analysis of Raw Cotton.—The following table gives the analysis of the cotton fiber from reports of the U. S. Department of Agriculture, representing the average of a large number of tests:

	Percent.
Water	6.74
Ash	1.65
Protein	1.50
Fiber (cellulose)	83.71
Nitrogen-free extract	5.79
Fat	0.61

An analysis of the fertilising constituents present in the cotton fiber is given as follows:

Fertilising Constituents

	Percent.
Water	6.07
Ash	1.37
Nitrogen	0.34
Phosphoric acid	0.10
Potash	0.46
Soda	0.09
Lime	0.19
Magnesia	0.08
Ferric oxide	0.02
Sulfuric acid	0.60
Chlorine	0.07
Insoluble matter	0.05

[1] *Jour. Soc. Chem. Ind.*, 1910, p. 249.
[2] *Ger. Pat.* 288,751 of 1914.
[3] *Papierfabrikant*, 1910, pp. 863, 890.
[4] *Jour. Soc. Dyers & Col.*, 1908, p. 106.
[5] *Jour. Soc. Dyers & Col.*, 1913, p. 9.
[6] *Jour. Soc. Chem. Ind.*, 1914, p. 902.
[7] *Färber Zeit.*, 1912, p. 379.
[8] *Zeitsch. angew. Chem.*, 1916, p. 397.
[9] *Jour. Soc. Dyers & Col.*, 1911, p. 142.

The composition of cotton fibers from different sources may be said to be practically the same, as variations in the reported analyses are no greater than the variations to be observed in the analyses of different samples of the same kind of cotton.

Balls [1] has determined the specific salinity of the cell-sap of pure strains of Egyptian cotton, and finds a salt content which varies not only with the salinity of the soil but also with the variety employed. Plants of two Egyptian strains growing with interlacing root systems showed differences of as much as 10.7 in the salinity of the cell-sap.

Lester [2] has studied the substances present in raw cotton capable of extraction by water. This extract is evidently of a complex nature and amounts to about 1.73 percent from yarn, though if the cotton yarn is cut up into short lengths ($\frac{1}{4}$ in.) the extractive matter rises to 2.11 percent. The analysis of this extract is given as follows:

	Percent.
Ash	39.22
Fatty acids (by HCl)	62.30
Ether extract	17.52
Cold water extract	39.50
Ash of original cotton	0.82
Ash of cotton after extraction with water	0.21

Lester also shows that while cotton on exposure to the air after drying will reabsorb about 8 percent of moisture, the dried aqueous extract from cotton will absorb about 32 percent, and hence is of a far different nature from that of cotton. Probably raw cotton owes some of its hydroscopic moisture to this substance.

The complete chemical analysis of cotton may be conducted as follows: First, the hygroscopic moisture may be determined by drying at 220° F. (or by the toluene method of Schwalbe); second, a weighed portion of the fiber is incinerated in a platinum or porcelain crucible to a complete ash; this will give the ash of the raw fiber, and it may be subsequently analysed by the customary chemical methods in order to ascertain its composition. Another portion of the fiber is boiled with caustic soda solution of 2° Tw., rinsed, and dried; the loss in weight is considered as fat and wax. Or the fibers may be extracted with alcohol and ether in a Soxhlet apparatus, and the extractive matter determined by loss in weight, or ascertained directly by evaporation of the solvent. The amount of nitrogen in the cotton may be determined by Kjehldahl's method. The amount of cuticle by determining the loss in weight, after boiling with sodium sulfite solution. The

[1] *Proc. Phil. Soc.*, 17, p. 467.

[2] *Jour. Soc. Chem. Ind.*, vol. 21, p. 388.

ash of the remaining cellulose can then be determined. A résumé of the complete analysis of cotton is as follows:

(*a*) Dry at 220° F. = hygroscopic moisture.
(*b*) Ignite; residue = ash of raw fiber.
(*c*) Boil with caustic soda = fat and wax.
(*d*) Bleach with sodium hypochlorite solution = coloring matters.
(*e*) Boil with alkaline solution of sodium sulfite = cuticular substance.
(*f*) Ignite; loss = cellulose.
(*g*) Residue of ignition = ash of cellulose.

Such an analysis will furnish about the following results:

	Percent.
(*a*) Hygroscopic water	7.00
(*b*) Ash of raw fiber	1.12
(*c*) Fats and wax	5.00
(*d*) Loss in bleaching	0.50
(*e*) Cuticular matters	0.75
(*f*) Pure cellulose	86.63
(*g*) Ash of cellulose	0.12

Knecht has made very exhaustive tests on the extraction of raw cotton yarns with various solvents and has studied the extractive matters obtained thereby.[1] The cotton material experimented with consisted of good qualities of American and Egyptian yarns of two-ply 40's count, containing 8.03 and 7.37 percent of moisture, respectively, after standing in an atmosphere containing 70 percent humidity. The amounts of ash in the samples were 0.93 and 1.06 percent, respectively. The following table gives the percentages of extracts obtained with the different solvents:

Extractions.	Knecht.		Knecht and Hall.		Knecht and Fernandes.	
	American.	Egyptian.	American.	Egyptian.	American.	Egyptian.
Benzene	0.55	0.47	0.41	0.44	0.43	0.45
Alcohol	0.90	0.68	0.53	0.74	0.54	0.75
Water	1.61	1.40	1.66	1.51	1.75	1.52
Ammonia	0.39	0.45	0.43	0.50	0.41	0.48
Formic acid	0.72	0.46	0.65	0.41	0.68	0.47
Hydrochloric acid	0.43	.....	0.66	0.59	0.58	0.57

Similar figures are given by Matthes and Streicher[2] who found that petroleum ether extracted 0.5 percent from Caravonica cotton (from

[1] *Jour. Soc. Dyers & Col.*, 1911, p. 255, and 1920, p. 43.
[2] *Pharm. Zeutr.*, p. 637.

North Queensland), 0.36 percent from Egyptian, and 0.34 percent from American. The same cottons after bleaching yielded 0.25, 0.26, and 0.32 percent, respectively. Piest [1] extracted nine samples of cotton with ether, carbon tetrachloride, and alcohol, and obtained small amounts of wax varying from 0.09 to 0.53 percent and Barnes [2] has found that ether extracts from 0.188 to 0.618 percent from various Indian cottons. Knecht [3] has recently noted that one effect of destroying the fibrous structure of the extracted cotton mechanically is to release a further quantity of extractive matter.

Apart from the wax, little is known about the material extracted save that it appears to contain much mineral matter. In the case of the cotton yarns examined by Knecht [4] the alcoholic extracts were amorphous, brown, and hydroscopic. They reduced Fehling's solution, and the ashes contained, respectively, 17.9 and 23.4 percent of potash, K_2O. The water extracts were similar, but did not reduce Fehling's solution so readily. They contained, respectively, 50.4 and 54.5 percent of mineral water.

Higgins [5] states that if cotton or linen is completely extracted with benzene, then treated with acid, washed and dried again, a further quantity of fatty acid, about 10 percent of the first amount of wax, may be obtained by boiling with benzene. The acid washings contain magnesium, from which the conclusion is drawn that some of the fatty acid is present as a magnesium salt. Knecht also reports that after extracting cotton with benzene and then bleaching, a further, but smaller, extract can be obtained.

The chief portion of the mineral matters present in the raw fibers is to be found in the water and alcohol extractions, as shown by the ash content of these extracts, as follows:

Extract.	Ash Content in Percent.	
	American.	Egyptian.
Alcohol	40.73	42.55
Water	48.27	50.09

The affinity of the cotton toward basic dyes shows no diminution after successive extraction with benzene, alcohol, and water. With tannic acid,

[1] *Zeitsch angew. Chem.*, 1921, p. 396.
[2] Dabney, *The Cotton Plant.*
[3] *Jour. Soc. Dyers & Col.*, 1920, p. 279.
[4] *Jour. Soc. Dyers & Col.*, 1918, p. 220
[5] *Bleaching*, p. 13.

on the other hand, the extracted cotton shows a less degree of absorption and also less power to retain that tannic acid absorbed. These results are shown in the following tables:

REACTION WITH TANNIC ACID

Extraction.	American.		Egyptian.	
	Absorbed, Gram.	Retained After Rinsing, Gram.	Absorbed, Gram.	Retained After Rinsing, Gram.
Original	0.0395	0.0295	0.0421	0.0240
Benzene	0.0326	0.0028	0.0339	0.0063
Alcohol	0.0291	0.0026	0.0307	0.0039
Water	0.0208	0.0019	0.0266	0.0066

It is evident, therefore, not only that less tannic acid is absorbed by the extracted cotton but that it is also more loosely held in combination.

The effect of the extractions on the tensile strength is shown as follows:

EFFECT OF EXTRACTIONS ON TENSILE STRENGTH

Extraction.	American.		Egyptian.	
	Conditioned, Ounces.	Dried at 100° C., Ounces.	Conditioned, Ounces.	Dried at 100° C., Ounces.
Original	12.19	13.32	15.34	15.51
Benzene	15.19	14.52	18.02	16.01
Alcohol	14.59	14.37	17.10	16.81
Water	16.12	15.92	15.45	15.59

One remarkable result in this connection is that the strength of the original cotton in the dried condition is greater than when the fiber has its normal amount of hydroscopic moisture.

4. Coloring Matter in Cotton.—The coloring matter of cotton has been investigated and has been found to consist of two organic pigments, the

one easily soluble in alcohol and the other dissolved only by boiling alcohol. According to Schunck,[1] the composition of these bodies from Nankin cotton is as follows:

	A. Soluble in Cold Alcohol, Percent.	B. Insoluble in Cold Alcohol, Percent.
Carbon	58.22	57.70
Hydrogen	5.42	5.60
Nitrogen	3.73	4.99
Oxygen	32.63	31.71

The composition of the analogous coloring matters in American cotton is practically identical with the above.

There is a peculiar variety of peeler cotton known as **blue bender** cotton. This fiber is characterised by a bluish color which cannot be bleached out by the usual methods employed for the bleaching of ordinary cotton. It receives its name from occurring in the "bends" of the Mississippi River valley. The exact nature of the color and the cause of its formation in this variety of cotton are not known. By some it is supposed that the defect arises from the plant being touched by frost too early, while others assume that the cause is to be found in some ingredient in the soil. Outside of its defective color and resistance to bleaching, the appearance and quality of the fiber are otherwise unimpaired.

It is a common opinion that brownish colored cottons contain more iron than lighter colored varieties. It appears, however, that the ash of dark colored cottons does not contain a greater proportion of iron. The coloring matter is altogether an organic pigment.[2]

Penot[3] observed that the coloring matter of cotton is soluble in alkalies, but not immediately; air and light, or chlorine, being necessary for its complete removal. Schunck[4] and Knecht[5] have isolated highly colored products containing nitrogen to which they are inclined to ascribe the color, but the conditions under which they were obtained, by soda ash and caustic soda boils, respectively, together with the analyses recorded by Schunck, render it probable that they are decomposed proteins. Still, it is possible that the coloring matter may occur in combination with protein. Taylor[6] has noted that the coloring matter present in cotton is eliminated completely by the use of a hypochlorous acid, or a hypochlor-

[1] *Chem. News*, 1868, p. 118; 1874, p. 5.
[2] Also see Kuhn, *Die Baumwolle*, p. 138.
[3] *Bull. Soc. Ind. Mulh.*, 1836, p. 369.
[4] *Manchester Lit. Phil. Soc.*, 1871, p. 95.
[5] *Jour. Soc. Dyers & Col.*, 1918, p. 220.
[6] *Jour. Soc. Dyers & Col.*, 1914, p. 85.

ite alone, and has drawn the conclusion that two coloring matters are present.

The pigment of cotton is most pronounced in wild varieties, the hairs of which are more or less colored by a reddish endochrome, especially in the parts more exposed to light. The color deepens as the cotton ripens, and W. L. Balls [1] states that a profound change occurs at about the twenty-seventh day of the development of the boll. The young bolls "pickle" in a mixture of alcohol and acetic acid to a green color, but the older bolls give a pink or bright red "pickle," and later, when the fruit is beginning to burst, the "pickle" is brown. The color is increased by exposure to diffused light, but is often destroyed by sunlight, especially when the protoplasm is dead. It is also deepened by steaming.[2]

In a recent communication [3] Brabhaj states that cottons varying in color from light green to dark brown have been cultivated. The fibers are extremely fine, and the brown variety is said to surpass in fineness any cotton hitherto produced.

The pigment is found chiefly in the lumen, but is also in association with the cellulose. Brazilian and South American cottons contain very little, but Egyptian cotton is so much richer in pigment that it can be readily distinguished thereby.

It is not known whether the pigment bears any relation to the "gossypol" of cotton seed [4] or to the glucosides found by A. G. Perkin [5] in cotton flowers.

5. Pectin compounds in Cotton.—Pectin compounds form the greater portion of the impurities present in cotton, and are very complex in nature. The term pectin is a rather broad one in a chemical sense, and relates to that class of bodies in fruit or plant juices that produce jelly-like compounds. The chemical nature and properties of the pectins are but little understood. The pectins form salts with metallic bases, so we may have calcium pectate, sodium pectate, and the like. When raw cotton is kier-boiled with caustic soda or caustic lime it is supposed that the pectin compounds are broken up from their complex organic combinations within the fiber and form sodium or calcium pectate. The gelatinous nature of cotton pectin is observable in the brown jelly-like masses to be found in the course of kier-boiling.

Schunck isolated from among the products removed from cotton by the soda ash boil considerable quantities of a substance corresponding with the "para-pectic acid" described earlier by Fremy. More recently,

[1] *Development and Properties of Raw Cotton*, p. 71.
[2] *Text. Mer.*, 1914, p. 85.
[3] *Dyer & Calico Ptr.*, 1920, p. 20.
[4] *Jour. Amer. Chem. Soc.*, 1918, p. 647.
[5] *Jour. Chem. Soc.*, 1909, p. 2181.

Knecht [1] obtained a similar product from the caustic soda boil which had been previously lime-boiled and soured. The material so obtained has received little attention, and the considerable literature on such products which has accumulated during the last decade is concerned chiefly with the pectic substance of sugar beet and of fruit juices.

On treatment with warm dilute sodium hydroxide, pectin loses methyl alcohol and is converted into pectic acid which is very soluble in alkali hydroxides, carbonates, or phosphates, and in most ammonium salts of organic acids. Ammonium oxalate gives a limpid solution, but alkali carbonates give mucilages. Its solutions in water are flocculated by the addition of salts. More prolonged action of alkali leads to meta-pectic acid, the ultimate product of the action of the usual bleaching agents. Pectic substances are almost entirely removed from the fiber in the scouring operations, which probably affect the decomposition of metallic salts. In a recent process [2] it is proposed to eliminate pectic matter by the use of hot hydrochloric acid; it is claimed that the fiber is not seriously weakened by the treatment. Ehrlich's work indicates that the pectin of the cell membranes of plants is the calcium-magnesium salt of a complex anhydro-arabino-galactose-methoxy-tetragalacturonic acid. There is no evidence as to the mode of linking, save that the arabinose group is weakly and the galactose group strongly held. Gartner considers that pectic acid is a galactose-galacturonic acid, rather than a tetragalacturonic acid.

6. Mineral Matter and Ash in Cotton.—The quantity of ash (mineral matter) in raw bale-cotton will average considerably higher than that obtained from the purified fiber; this is due to adhering sand and dust which are nearly always present. The following table shows the amount of ash contained in samples of different varieties of cotton:

	Percent.
Dharwar	4.16
Dhollerah	6.22
Sea-island	1.25
Peruvian (soft)	1.68
" (rough)	1.15
Bengal	3.98
Broach	3.14
Oomrawuttee	2.52
Egyptian (brown)	1.73
" (white)	1.19
Pernambuco	1.60
American	1.52

Monie gives a table showing the percentage of sand or mineral matter contained in bales of commercial cotton as they arrive at Liverpool.

[1] *Jour. Soc. Dyers & Col.*, 1918, p. 220
[2] *Brit. Pat.* 104,202 of 1916.

	Percent.		Percent.
Sea-island	1.10	Upland	2.10
Rough Peruvian	1.25	Bahia	2.16
Gallini Egyptian	1.25	Hingunghat	2.33
Brown Egyptian	1.60	Broach	2.58
Orleans	1.60	Oomrawuttee	2.93
White Egyptian	1.75	African	3.20
Smooth Peruvian	1.80	Dhollerah	4.10
Pernambuco	1.98	Comptah	4.18
Texas	2.10	Bengal	5.30

It is to be presumed that Monie did not include in the above figures the amount of mineral matter in cotton as obtained from the ash of the purified fiber, but that his figures represent the sand or other foreign mineral matter mechanically held in the baled cotton.

When the amount of ash is found to be much over 1 percent, the excess may be considered as mechanically attached sand and dust. Barnes contends that this is incorrect; twelve Indian cottons, he found, average 2.48 percent; the extreme values being 1.34 and 3.99. The amounts of silica and chlorine present were in accord with the figures for total ash. Five samples of American cotton gave values ranging from 1.18 to 1.92, while two Egyptian samples gave 1.37 and 1.50, respectively. On the other hand, a two-ply 60's American cotton examined by Knecht [1] contained only 0.93 percent, a similar Egyptian sample 1.17, and a soft twist Egyptian 0.89 percent of ash. Two complete analyses of the ash are quoted by Barnes, as follows:

	Bombay, Percent.	Punjaub, Percent.
Moisture in original fiber	2.23	3.78
Total ash in dry fiber	3.99	1.85
Constituents of the ash: SiO_2	15.56	14.40
Al_2O_3	10.80	12.87
Fe_2O_3	5.89	1.92
CaO	9.75	10.65
MgO	1.87	4.36
K_2O	27.32	26.03
Na_2O	4.51	8.40
SO_3	1.96	2.52
P_2O_5	3.26	4.46
CO_2	12.19	8.03
Cl	6.55	3.84
Undetermined	0.34	2.52

[1] *Jour. Soc. Dyers & Col.*, 1918, p. 220.

The true ash of the cotton fiber consists principally of the carbonates, phosphates, chlorides, and sulfates of potassium, calcium, and magnesium, as is exhibited by the following analysis of Dr. Ure:

	Percent.
Potassium carbonate	44.80
" chloride	9.90
" sulfate	9.30
Calcium phosphate	9.00
" carbonate	10.60
Magnesium phosphate	8.40
Ferric oxide	3.00
Alumina and loss	5.00

Mitchell and Prideaux[1] give analyses of typical specimens of cotton, as follows:

Variety of Cotton.	Moisture, Percent.	Mineral Matter, Including Sand, Percent.	Phosphoric Acid as P_2O_5, Percent.
Sea-island	7.83	2.21	0.22
Orleans	7.70	2.05	0.18
Pernambuco	8.85	2.08	0.37
Indian (Oomaa)	7.27	2.86	0.23
Indian (Bengal)	7.89	3.30	0.15

The analyses of Davis, Dreyfus, and Holland, reported as a mean from twelve different varieties of cotton, show a little difference from the above analyses, especially in having present sodium carbonate as one of the constituents. The mean of these analyses is given as follows:

	Percent.
Potassium carbonate	33.22
" chloride	10.21
" sulfate	13.02
Sodium carbonate	3.35
Magnesium phosphate	8.73
" carbonate	7.81
Calcium carbonate	20.26
Ferric oxide	3.40

According to Calvert,[2] cotton samples from different countries contain the following percentages of phosphoric acid soluble in water:

Egypt	0.055	Surat	0.027
New Orleans	0.049	Carthagena	0.035 to 0.050
Bengal	0.055	Cyprus	0.050

It is sometimes found that mercerised Egyptian cotton contains a larger percentage of iron than is naturally present in the untreated fiber. This

[1] *Fibers Used in Textile Industries*, p. 96. [2] *Jour. prakt. Chem.*, 1869, p. 122.

is doubtless caused by the presence of iron in the caustic soda solution employed for the mercerisation; sodium ferrate, in fact, appears to be a normal constituent of such solutions, being derived from the solvent action of caustic soda on the iron rust present in the tanks. Lefêvre [1] gives the following analyses of samples of mercerised Egyptian cotton:

Kind of Cotton.	Ash, Percent.	Oxide of Iron, in Ash, Percent.	Color of Ash.
Natural Egyptian	0.624	1.50	White
Mercerised Egyptian	0.137	8.02	Greenish
Gray mercerised Egyptian	0.403	2.31	Yellow gray
Bleached mercerised Egyptian	0.088	5.45	Greenish

The mineral matter present in cotton is speedily, but not completely, eliminated during the usual bleaching operations, the total loss at each stage being given by Hebden [2] as follows:

Steep. Percent.	First Boil. Percent.	Second Boil. Percent.	Chemic. Percent.	Sour. Percent.
70.5	87.3	95.4	93.0	95.0

Knecht [3] reports that after lime boil, sour, soda boil, sour, chemic and sour with hydrochloric acid, the ash of a soft twist Egyptian sample had decreased from 0.89 to 0.15 percent.

Lester [4] has compared the ash from the aqueous extract of cotton with that of the cotton itself. The latter contained 0.82 percent, and 0.61 percent was removed by the extraction. The constituents were as follows:

	Ash of Water Extract, Percent.	Ash of Cotton, Percent.
Magnesium carbonate	6.84	5.11
" phosphate	2.65	13.10
Alumina	3.90	3.90
Iron oxide	Trace	2.71
Silica	1.79	1.00
Calcium carbonate	3.80	13.50
Sodium carbonate	27.78	15.90
Potassium carbonate	13.82	
" sulfate	36.9	32.2
" chloride	2.60	2.5
Sodium sulfate	.....	4.6
" "	.....	4.6

[1] *Rev. Gen. Mat. Col.*, 1909, p. 281.
[2] *Jour. Ind. Eng. Chem.*, 1914, p. 714.
[3] *Jour. Soc. Dyers & Col.*, 1918, p. 220.
[4] *Text. Mer.*, Dec., 1904.

Lester considers the hydroscopic properties of cotton to be due to some extent to the material extracted by water. Grace Calvert [1] found that nearly the whole of the phosphorus was removed by cold water extraction, and determined the phosphate content of a number of cottons. The percentages of soluble phosphate, calculated at P_2O_5, are as follows:

	Percent.		Percent.
Egypt	0.055	Carthagena	0.035
New Orleans	0.049	Macao	0.050
Bengal	0.055	Cyprus	0.050
Surat	0.027		

When a sample of lint is burnt, the skeletal structure is preserved in the ash, which suggests that the mineral substances are present in the tissue of the fiber itself rather than as dried-up cell-sap.

7. Nitrogenous Matter in Cotton.—The albuminous or nitrogenous matter present in cotton is only of very small amount, and doubtless consists of protoplasmic residue. Different varieties of cotton, on analysis, show the following percentages of nitrogen; some of this, however, may be derived from mineral nitrates which may be present in slight amount in the fiber (Bowman):

	Percent Nitrogen.
American	0.30
Sea-island	0.34
Bengal	0.39
Rough Peruvian	0.33
Egyptian (white)	0.29
" (brown)	0.42
Mean	0.345

According to analyses by Schindler,[2] raw Egyptian cotton gave 2.50 percent of nitrogen. By boiling the cotton for eight hours with caustic soda solution the amount of nitrogen was reduced to 0.064 percent.

It is likely that in the process of bleaching most of the albuminous matter is removed from the cotton fiber. Haller has shown that bleached cotton is not tinted so deeply as raw cotton with an acid solution of Safranine, and he concludes that this is due to the albuminous matter acting as a mordant for the dyestuff.

The amount of nitrogenous matter present in cotton may be determined by Kjehldahl's process, as follows: 5 grams of cotton material is chopped up and heated in a flask with 30 cc. of concentrated sulfuric acid and 2 grams of potassium permanganate. This treatment results in a complete decom-

[1] *Jour. Chem. Soc.*, 1867, p. 303.
[2] *Jour. Soc. Dyers & Col.*, 1908, p. 106.

position of the nitrogenous matter with the liberation of ammonia, which immediately combines with the sulfuric acid present to form ammonium sulfate. An excess of caustic soda solution is now carefully added, and the solution boiled. This results in the liberation of free ammonia as a gas. The latter is passed into a definite volume of $\frac{1}{10}$ normal sulfuric acid solution, and the excess of acid not neutralised by the ammonia is subsequently titrated with $\frac{1}{10}$ normal caustic soda solution, using methyl orange as an indicator. The amount of sulfuric acid neutralised measures the quantity of ammonia formed, which in turn determines the amount of nitrogen present in the original cotton. The quantity of nitrogen so obtained multiplied by the factor 6.4 gives the amount of nitrogenous matter present as an albuminoid.

Rather recent tests on typical cotton furnished the following results: American cotton gave 0.138 percent of nitrogen; Texas cotton 0.150 percent, and red Peruvian 0.280 percent.

Knecht [1] has examined the removal of nitrogenous constituents by extraction with a number of solvents, his results with an American cotton containing 0.204 percent being as follows:

After Successive Extraction with	Nitrogen Content.	
	American, Percent.	Egyptian, Percent.
Benzene	0.189	0.240
Alcohol	0.184	0.226
Water	0.175	0.218
Ammonia (dilute)	0.175	0.218
Formic acid (dilute)	0.168	0.211
Hydrochloric acid (2° Tw.)	0.138	0.175
Bleaching powder (2° Tw.)	0.022	0.037

Treatment with inert solvents thus accounted for 14.1 and 16.7 percent of the nitrogen in the respective complex, and chemical treatment for 72.3 and 71.3 percent.

Knecht and Fernandez [2] have suggested that as an albuminoid has been obtained from raw cotton, dye affinity may be attributed to a definite substance, and in this connection it is worth recording that R. J. Flintoff [3] has discussed the function of added albuminoids as fixing agents in the

[1] *Jour. Soc. Dyers & Col.*, 1918, p. 220.
[2] *Jour. Soc. Dyers & Col.*, 1920, p. 43.
[3] *Jour. Soc. Chem. Ind.*, 1896, p. 235.

dyebath. Haller [1] has also shown that there is a substance in the cotton fiber which has an affinity for stannous chloride.

The effect of bleaching operations on the nitrogenous constituents has been examined by Schindler,[2] who found that after boiling with sodium hydroxide of 2° Tw. for eight hours the nitrogen content of an Egyptian cotton was reduced from 0.250 to 0.065 percent. Increase of the concentration of sodium hydroxide to 10° Tw. reduced the nitrogen to 0.028 percent, while further treatment with bleaching powder of 1.5° Tw. reduced it to 0.003 percent. Using a still stronger solution of sodium hydroxide (77° Tw.), the percentage of nitrogen was reduced to 0.016 to 0.019. Most of the nitrogen expelled from the cotton remained in some form in the solution, and was not isolated as ammonia. The figures obtained by Higgins for the elimination of nitrogen as ammonia by the method of Osborne, Leavenworth, and Brautlecht confirm this, an American yarn yielding only 0.018 percent, and an Egyptian 0.034 percent, of nitrogen as ammonia.

Knecht [3] gives the following figures for the various stages of the bleaching process, the nitrogen being expressed in terms of that originally present:

After	Percentage of Nitrogen Originally Present which Survives Treatment.
Lime boil	54.0
Sour (HCl)	40.5
Caustic soda boil	27.1
Chemic	6.7
Sour (HCl)	16.8
Sour (HCl)	5.8

The first three extracts were examined. The first contained 3.7 percent of nitrogen, but did not give a protein reaction. Treatment with alcohol precipitated a gelatinous substance resembling Schunck's pectic acid. The second yielded stearic acid and a small proportion of cotton wax, and the third, which contained 3.46 percent of nitrogen, appeared to consist mainly of brown coloring matter.

Higgins [4] found that unsized yarn loses about one-third of its protein on steeping in salt solution, and formed the opinion that the usual process of scouring with caustic soda or by the "lime sour soda wash" sequence removes all the protein. The treatment leaves about 8 percent of the nitrogen unaccounted for, and it is suggested that this residuum must be non-protein nitrogen, since Hebden [5] found that the first boil effected the removal of all the phosphorus but only 91.5 percent of the nitrogen.

[1] *Text. Forschung*, 1920, p. 22.
[2] *Jour. Soc. Dyers & Col.*, 1908, p. 106.
[3] *Jour. Soc. Dyers & Col.*, 1918, p. 220.
[4] *Jour. Soc. Dyers & Col.*, 1919, p. 169
[5] *Jour. Ind. Eng. Chem.*, 1914, p. 714.

The total loss of nitrogen after different bleaching processes is given as follows: First boil, 91.5 percent; second boil, 91.7 percent; chemic, 92.2 percent; sour, 92.7 percent.

The importance of the complete removal of the nitrogenous substances in cotton is emphasised by Trotman [1] who has found that nearly all cases of bacterial damage to finished goods are associated with high nitrogen content.

[1] *Jour. Soc. Chem. Ind.*, 1909, p. 1237.

CHAPTER XVI

CELLULOSE AND ITS CHEMICAL PROPERTIES

1. Cellulose.—This is one of the most important of the naturally occurring chemical compounds, as it forms the basis of all vegetable tissue. Chemically it consists of carbon, hydrogen, and oxygen, and has the empirical formula $C_6H_{10}O_5$.

The cellulose of all vegetable tissues, even in a highly purified condition, appears to contain a small amount of mineral constituents, apparently forming an integral or organic portion of the fiber structure. The amount of ash, for instance, obtained from bleached cotton is about 0.1 to 0.4 percent. Even "Swedish" filter-paper, which has been treated with hydrochloric and hydrofluoric acids for the removal of inorganic constituents, will still contain from 0.03 to 0.05 percent of ash.

Cellulose belongs to a class of bodies known as *carbohydrates*, and is closely related to the starches, dextrines, and sugars. Chemically considered, these compounds must all be regarded as alcohols containing aldehydic and ketonic groups.

Though cellulose appears to be somewhat analogous to these bodies, it nevertheless differs from them in its much greater resistance to the hydrolytic action of acids, alkalies, and enzymes. The latter reagents readily split up the starches into simpler bodies; but no such reaction, through artificial means at least, has been observed in the case of cellulose. That such a reaction, however, takes place in the tissues of the growing plant there is no doubt.

The word "cellulose" must not be taken as signifying a simple definite substance of unvarying properties, but rather as a generic term including quite a number of bodies of similar chemical nature. Like starch and other complex carbohydrates of organic physical structure, cellulose will vary somewhat in its properties, depending upon its source or derivation. As a class the celluloses exhibit certain chemical characteristics, by means of which they may be distinguished from associated bodies of allied chemical constitution. Physically they are colorless amorphous substances capable of withstanding rather high temperatures without decomposition. They are insoluble in nearly all of the usual solvents, such as water, alcohol, ether, etc., but dissolve more or less completely in an ammoniacal solution

of copper oxide (Schweitzer's reagent)[1] and in solutions of zinc chloride and phosphoric acid. Deming[2] states that cellulose (in the form of filter-paper) is also soluble in concentrated aqueous solutions of antimony trichloride, stannous chloride, and zinc bromide. Solution in these reagents apparently takes place without decomposition, as the cellulose may be precipitated unchanged therefrom by the addition of acids and various salts, the precipitate being known as "regenerated" cellulose. Cross and Bevan attribute the solution of cellulose in cuprammonium to the preliminary formation of a soluble gelatinous hydrate induced by the presence of the copper. That the alteration in the cellulose is merely structural has been disputed, by reason of the fact that filaments prepared from the precipitated cellulose have a greatly increased affinity for dye-stuffs; they appear to act more as a hydrocellulose.

Cross and Bevan make the following remarks respecting the preparation of the ammonical solution of copper oxide: The solutions of cuprammonium compounds generally, in the presence of excess of ammonia, attack cellulose rapidly in the cold, forming a series of gelatinous hydrates, passing ultimately into fully soluble forms. The solutions of the pure cuprammonium hydroxide are more active in producing these effects than the solutions resulting from the decomposition of a copper salt with excess of ammonia. Two methods are in common use for the preparation of these solutions, which should contain 10 to 15 percent of ammonia and 2 to 2.5 percent of copper as the oxide. (1) Hydrated copper oxide is prepared by precipitating a solution of copper sulfate of 2 percent strength with a slight excess of a dilute solution of sodium hydrate. The precipitate is washed until it is entirely free from alkali. The original solution in which the solution takes place, as well as the water used in washing, should contain a small quantity of glycerol. The washed precipitate is well drained, and then mixed with a quantity of a 10 percent solution of glycerol, in contact with which it may be preserved unchanged in stoppered bottles. When desired for use, the oxide is washed free from glycerol and dissolved in ammonia water (of 15 to 20 percent strength). (2) Metallic copper, in the form of sheet or turnings, is placed in a cylinder and covered with strong ammonia; atmospheric air is caused to bubble through the column of liquid at a rate calculated to 40 times the volume of the liquid used per hour. In about six hours a liquid of the requisite composition is obtained. Solutions containing 5 to 10 percent of cellulose are readily prepared by digestion in the cold with 10 to 20 times the weight of cuprammonium solution, a rather ropy or gelatinous solution being obtained. The cellulose is readily precipitated from the solution: (*a*) By the addition of

[1] According to Cross and Bevan, the solubility of cellulose in ammoniacal copper oxide was first discovered and described by John Mercer.

[2] *Jour. Amer. Chem. Soc.*, 1911, p. 1515.

neutral dehydrating agents, such as alcohol, sodium chloride, and other salts of the alkalies, and (*b*) by the addition of acids, in which case the cellulose is precipitated in the pure state, or free from copper oxide.

Cellulose undergoes change very readily, the chief modifications being (*a*) hydration, now regarded as an absorption phenomenon of the colloid cellulose, (*b*) oxidation, (*c*) acid hydrolysis, and (*d*) "depolymerisation." The first modification is roughly estimated by means of the absorptive power of the material, under empirical conditions, for iodine,[1] substantive dyes, cupric hydroxide from Fehling's solution or sodium hydroxide. Another approximate method for ascertaining the extent to which cellulose is "modified" is to determine its solubility in sodium hydroxide. Schwalbe[2] used a 5 percent and Jentgen[3] a 17.5 percent solution. The process is employed mainly in distinguishing various types of artificial silks. The most important clues to "modification" are afforded, however, by determining (*a*) the "copper number"—that is, the number of grams of copper reduced from Fehling's solution by 100 grams of the cellulose, the value being below 1 for purest bleached cotton and rising to as much as 16 in the case of oxidised cellulose, and (*b*) the viscosity in ammoniacal cupric hydroxide solutions. The latter method has been investigated very thoroughly in the Research Department, Woolwich Arsenal,[4] where it proved successful after it was recognised that bright light and air must be excluded from the solution, that the cuprammonium solution must be fairly constant, and that the "falling sphere" viscometer is the most convenient measuring instrument. It is found that cotton treated with alkali hydroxides gives much less viscous solutions in "cuprammonium" than untreated cotton, and that the viscosity of nitrated cotton (in mixtures of alcohol and ether) varies according to the viscosity of solutions of the original cotton. Nitrated raw cotton gives the most viscous solutions, which fact suggests that the action of sodium hydroxide may be of the nature of "depolymerisation."

2. Preparation of Pure Cellulose.—In order to obtain pure cellulose for chemical purposes it is customary to treat cotton successively with dilute caustic alkali, dilute acid, water, alcohol, and ether. Cross and Bevan recommend the following procedure in the isolation of pure cellulose in the study of the vegetable fibers: (*a*) The fibrous raw material is boiled with a dilute (1 to 2 percent) solution of caustic soda, and, after thorough washing, is (*b*) exposed in the moist state to an atmosphere of chlorine gas; (*c*) it is again treated with boiling alkali. By such treatment the "non-cellulose" constituents of most vegetable fibers are removed, and a

[1] *Jour. Soc. Chem. Ind.*, 1908, p. 105.
[2] *Die Chemie der Zellulose*, p. 636.
[3] *Kunstoffe*, 1911, p. 165.
[4] *Jour. Chem. Soc.*, 1920, pp. 473–78.

residue of pure cellulose is obtained. A subsequent slight treatment with a dilute solution of chloride of lime for the removal of traces of coloring matters, and a final washing with alcohol and ether completes the purification.

The result of this treatment is to remove all foreign and encrusting materials from the raw fiber, and possibly also to remove the thin, external cuticular membrane which may be chemically different from the rest of the tissue. The specific gravity or density of cellulose as obtained in the usual manner is about 1.5, and this also represents the density of cotton and most other plant fibers.

Beltzer describes the following method for the preparation of normal pure cellulose from cotton: (*a*) The cotton is first carefully combed in order to remove mechanically all dirt and foreign matter; (*b*) it is then boiled for six to eight hours in a solution of caustic soda of $2\frac{1}{2}°$ Tw. The liquor is then squeezed out and the cotton rinsed until the wash-water is no longer colored; (*c*) the cotton is next treated with a solution of hydrochloric acid of 2° Tw. and at 120° F. for three to four hours; then washed in warm water; (*d*) the fiber is then bleached in a solution of sodium hypochlorite at 2° Tw. at a temperature of 80° F. for six to eight hours, after which it is rinsed in lukewarm water and squeezed; (*e*) a second treatment with acid is then given similar to the first, and the cotton is again well rinsed; (*f*) the cotton is finally treated with a solution of sodium bisulfite of 2° Tw. at 120° F. for five hours, then well rinsed in lukewarm distilled water. The cotton is then squeezed and dried at a moderate temperature. The analysis of this dried cellulose should correspond to $C_6H_{10}O_5$, and the ash on ignition should not exceed 0.05 percent. This cellulose should not contain either hydrocellulose or oxycellulose, the presence of which may be detected by sensitive qualitative tests. This normal pure cellulose should be very resistant to the action of caustic alkalies; after prolonged treatment with boiling dilute caustic soda solution, followed by washing, acidulation, and rinsing the weight of the cellulose should remain constant. Any loss will indicate partial solution due to presence of hydrocellulose or oxycellulose, both of which are soluble in caustic soda. To remove these impurities the cotton should be again boiled with a solution of caustic soda of 2° Tw., rinsed in distilled water, aciduated at 120° F., with a solution of hydrofluoric acid of $1\frac{1}{2}°$ Tw., washed, treated with bisulfite, finally thoroughly rinsed, squeezed, and dried again. On distillation with hydrochloric acid this purified cellulose should not give any furfural, nor give a rose color with phloroglucinol-hydrochloric acid reagent, and its copper index with Fehling's solution should be zero or nearly so.

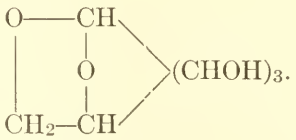
3. Chemical Constitution of Cellulose.—Chemically considered, cellulose is a derivative of the open-chain or paraffin series of hydrocarbons,

and furthermore it exhibits the reactions of a saturated compound. As with the other carbohydrates, chemists have found it a matter of great difficulty to ascertain even approximately the true molecular formula of cellulose. Though its empirical formula is $C_6H_{10}O_5$, this in no way represents the true molecular complexity of the substance. From a study, however, of its various synthetical derivatives, with special reference to its esters, such as the acetates, benzoates, and nitrates, the provisional formula of $C_{12}H_{20}O_{10}$ has been given to the cellulose molecule. The nature and position of the various organic groups present in this molecular formula, however, have yet to be explained.

The fact that cellulose can exist in the colloidal condition, and is difficultly soluble is not considered as indicating, as previously supposed, a high molecular weight, for both alumina and silicic acid exist in the colloidal state and it is not necessary to assume a high molecular weight for these bodies.

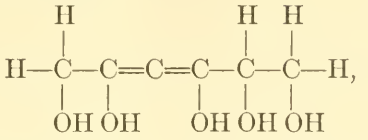
There has been a considerable amount of speculation among chemists as to the chemical nature and constitution of cellulose, but there has been so few experimental data on which to frame an intelligent theory, that most of these speculations are mere scientific guesswork, and have little more than a provisional value. From the action of zinc chloride on cellulose it has been presumed that the cellulose molecule contains hydroxyl groups of such a nature as to give it a saltlike property, and the solution of the cellulose in the zinc chloride is supposed to be due to the formation of a kind of double salt. There also appears to be a chemical reaction of limited degree between cellulose and dilute solutions of caustic alkalies and mineral acids. According to Mills, the relative molecular ratio of the absorption by cellulose of alkalies and acids is represented by 10NaOH : 3HCl. From this and other considerations, it would appear that cellulose exhibits the properties of a feeble acid and of a still more feeble base.

Vignon has proposed to give cellulose the following constitutional formula:

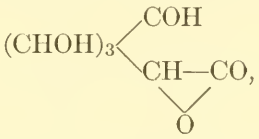


This is based on a study of the highest nitrate of cellulose and the decomposition of the nitrate by alkalies with formation of hydroxypyruvic acid. The structure given, however, is more or less hypothetical in nature, and needs experimental confirmation in many particulars before

it can be accepted without question. The older chemical configuration of cellulose given by Bowman,

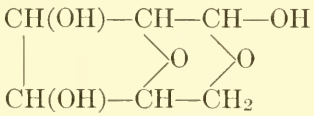


is without any experimental reason for its existence, and the idea that it contains an unsaturated carbon grouping, —C=C—, has been proved erroneous. From a study of the osazones of oxycellulose, Vignon has ascribed to this latter body a constitutional formula having the group, in union with varying proportions of residual cellulose.

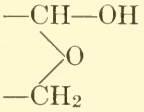


The existence of a compound containing cellulose and sulfuric acid in the proportion $4C_6H_{10}O_5 : H_2SO_4$ is put forward as a proof that in its reactions cellulose behaves like a complex molecule of at least 24 carbon atoms.

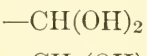
Green, however, believes the simple formula $C_6H_{10}O_5$ as amply justified. He considers the adoption of $C_{12}H_{20}O_{10}$ as the proper formula, based on the existence of tri- and pentanitrates, as erroneous, and considers the existence of such nitrates as very doubtful. He proposes the following constitutional formula for cellulose:



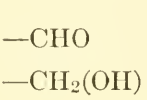
and claims that such a formula exhibits the aldehydic nature of cellulose as follows:



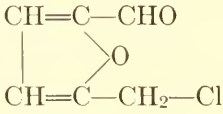
which by fixation of water becomes:



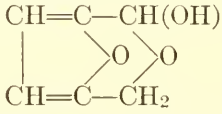
and then:



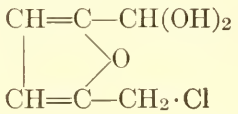
This formula is also in accord with the formation of trinitro and triacetyl derivatives as the limits of esterification of cellulose, for higher derivatives could only be obtained by the transformation of the two central oxygen atoms into two hydroxyl groups. It also explains why cellulose does not react with either phenylhydrazine or hydroxylamine, as it does not contain carbonyl (CO) groups, either ketonic or aldehydic; while, on the other hand, by simple hydrolysis it yields derivatives containing the carbonyl group. Green considers the existence of a tetracetate of cellulose as doubtful, but even if such does exist, its formation is probably due to a hydrolysis which precedes the acetylisation. According to Fenton, when cellulose is treated with dry hydrochloric acid gas without heating, there is formed chlormethyl-furfural:



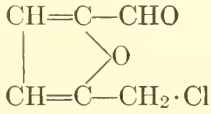
Green claims that his formula explains this remarkable reaction. By hydration there is first formed the intermediate compound:



which gives by addition of hydrochloric acid:



and by elimination of water:

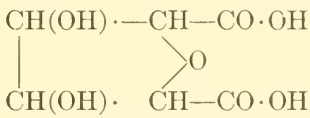


The intermediate product assumed by Green in the Fenton reaction, appears to have the same empirical formula as *lignin*, $C_6H_6O_3$, a substance associated with cellulose in woody fiber. This would seem to furnish a physiological explanation of the relation which exists between lignin and cellulose. The color reactions observed by Fenton with his new derivatives would also seem to demonstrate this.

Recent work in the constitution of cellulose indicates that the generally accepted formula for starch, cellulose, etc. $(C_6H_{10}O_5)n$, is incorrect, and should be replaced by $(C_6H_{10}O_5)n \cdot H_2O$.[1]

[1] See H. Kiliani, *Chem. Zeit.*, 1908, p. 366.

Green states that a successful formula for cellulose must explain the following facts: (1) A trinitrated derivative; (2) a triacetyl derivative; (3) with concentrated caustic soda cellulose gives a compound which is decomposed by water to form cellulose hydrate (mercerising), which is much more soluble than cellulose itself in solutions of ammoniacal copper oxide and zinc chlorides; (4) treated with carbon disulfide the alkali cellulose is converted into cellulose thiocarbonate (viscose), which is easily soluble in water; (5) cellulose does not react with phenylhydrazine or hydroxylamine; (6) as an ultimate product of hydrolysis (with sulfuric acid) cellulose gives glucose; (7) Fenton's reaction or the formation of chlormethyl-furfural; (8) the formation of oxycellulose by the oxidation of cellulose; this body has properties very similar to cellulose itself, but has a decided acid character, and when distilled with dilute sulfuric acid it gives furfural; (9) when oxycellulose is boiled with milk of lime it gives dioxybutyric acid and iso-glucosic acid (Faber and Follens):



(10) nitrocelluloses, when treated with dilute caustic soda, give oxypyruvic acid (Will): $CH_2(OH)\cdot CO\cdot CO\cdot OH$.[1]

Regarded from the point of view of the ionic theory, cellulose is considered as a molecular aggregate consisting of a mixture of ions of varying dimensions. Hence, cellulose as a typical colloid has no definite reactive unit as a body which takes the crystalline form, nor a fixed molecular constitution which may be represented in the limits of a constitutional formula; for the cellulose molecule cannot be regarded as a static unit, but rather as a dynamic equilibrium; its reacting unit at any time being a function of the conditions surrounding it. This view of the constitution of cellulose has been advanced by C. F. Cross.

[1] Many chemists by studying various compounds of cellulose have suggested a number of different molecular formulas for this compound. Cross and Bevan in studying the cellulose xanthates arrive at rather simpler formula than Green. Eder (*Berichte*, 1880, p. 169) adopted the formula $(C_6H_{10}O_5)_2$ for cellulose, from the fact that he obtained four different nitration steps between mono- and trinitrocellulose. Vieille (*Comptes rendus*, 1882, p. 132) observed eight intermediate nitration steps, and consequently adopted the formula $(C_6H_{10}O_5)_4$, and this was also accepted by Lunge and Bebie (*Zeit. ang. Chem.*, 1901, p. 507). Mendelejeff (*Monit. Sci.*, 1897, p. 510) adopted the formula $(C_6H_{10}O_5)_5$ on a basis of his analyses of various nitrated celluloses. Bumcke and Wolffenstein (*Berichte*, 1899, p. 2493) arrived at the formula $(C_6H_{10}O_5)_{12}$ through a study of the action of hydrogen peroxide on cellulose leading to the formation of a compound they called "hydralcellulose." Tollens (*Kohlenhydrate*, vol. 1, p. 231) adopted the formula $(C_6H_{10}O_5)_{30}$, while Skraup (see Piest, *Die Zellulose*, p. 137) proposed the formula $(C_6H_{10}O_5)_{34}$.

4. Chemical Reactions of Cellulose.—In its chemical reactions cellulose is particularly inert, combining with only a few substances, and then only with great difficulty and under peculiar conditions. It is quite resistant to the processes of oxidation and reduction, and hydrolysis and dehydration. This high degree of resistance to hydrolysis (alkaline) and oxidation belongs only to cotton cellulose and to the group of which it is the type, and which includes the cellulose of flax, ramie, and hemp. A large number of celluloses, on the other hand, are distinguished by considerable reactivity, due to the presence of " free " carbonyl groups, and are therefore more or less easily hydrolysed and oxidised. The hydration of cellulose is a common occurrence in the manufacture of paper, being brought about by a prolonged beating of the fiber in the engine, with the result that the fibers become quite gelatinous and the resulting sheet of paper is more or less transparent. This process is used in the manufacture of imitation parchment paper and grease-proof paper. The sheet is highly transparent and when heated with a lighted match underneath it becomes blistered. The celluloses of the cereal straws and esparto grass are of this type, hence the relative inferiority of the papers into the composition of which they enter. Cotton cellulose is also distinguished by the fact that it gives no furfural when distilled with acid, and by being precipitated unchanged from its solution in alkaline carbon disulfide. Concentrated sulfuric acid dissolves cellulose with the production of a viscous solution; dilution with water causes the precipitation of an amorphous substance known as **amyloid,** a starch-like body having the formula $C_{12}H_{22}O_{11}$, and like starch it is colored blue with iodine. On this reaction is based the method of testing for cellulose, by applying sulfuric acid and iodine. On boiling with dilute sulfuric acid, cellulose is converted into dextrin and glucose. In the hydrolysis of cellulose, as for instance by boiling with dilute sulfuric acid, it is converted into a carbohydrate having the composition $C_6H_{12}O_6$, in accordance with the following equation:

$$C_6H_{10}O_5+H_2O=C_6H_{12}O_6$$

On heating with acetic anhydride to 180° C., cellulose is converted into an acetyl derivative having the formula $C_{12}H_{14}O_4(OCOCH_3)_6$. Cellulose does not react directly with acetic anhydride, but at the temperature above given and with six times its weight of the anhydride it gives the derivative having the above formula, and which may be called the triacetate. With a smaller quantity of acetic anhydride, a mixture of lower acetates is obtained which are insoluble in glacial acetic acid. The triacetate is readily soluble in this acid, however, and also in nitrobenzene. Its solutions are very viscous. Regenerated cellulose, prepared by pre-

cipitation of viscous solutions, reacts with acetic anhydride directly, and gives what appears to be the tetracetate.[1]

5. Hydrocellulose.—By the moderated action of concentrated acids and various acid salts, cellulose appears to undergo a process of hydrolysis, being converted into a friable amorphous body known as **hydrocellulose.**[2] This reaction is of importance in the carbonising process for removing vegetable matter from woolen goods.[3]

Hydrocellulose appears to be a combination of cellulose with one molecule of water, and has been given the formula $C_{12}H_{22}O_{11}$. The formation of hydrocellulose from cotton results in structural disintegration so that the fiber may easily be reduced to a powder.

When any cellulose fiber is exposed to the action of dilute acids under certain conditions, its tenacity is destroyed, and it falls to a powder which is presumably hydrocellulose. When the above reaction takes place, however, instead of a gain in weight as theory would indicate, there is invariably a loss and a small amount of soluble matter is formed, a portion of which in all probability is *d*-glucose.[4] The elementary composition of the powder is also shown to be identical with that of cellulose, the previous statements on this point being claimed to be founded on faulty experimental methods. A hydrated cellulose is not formed under these conditions, but a hydrolysis takes place similar to that undergone by other carbohydrates under comparable conditions.

Hydrocellulose is also of considerable technical importance, as it is much more reactive than ordinary cellulose, and so is employed for the production of the nitric and acetic acid compounds of cellulose, as the hydrocellulose compounds are much more soluble in the solvents employed.

Hydrocellulose is also manufactured for the purpose of making guncotton, being used in place of cotton; for when treated with the necessary acid mixture it furnishes a more sensitive guncotton which explodes more rapidly and therefore is better adapted for the making of detonating fuses.

Hydrocellulose may be prepared by treating a mixture of cotton and potassium chlorate with hydrochloric acid at a temperature of 60°–70° C.[5]

[1] For further remarks concerning the acetylation of cellulose see Cross and Bevan, *Cellulose* and *Researches on Cellulose*.

[2] Girard, in 1875, was probably the first to investigate hydrocellulose. He prepared it both by steeping cotton for twelve hours in sulfuric acid of 45° Bé., and by impregnating cotton with 3 percent sulfuric acid solution, then drying and heating.

[3] Carbonising as a technical process was apparently first introduced by Köber in Canstatt in 1852 for the recovery of wool from wool-cotton rags. Later on, Frézon and Isart took out patents in France and England for the carbonising of raw wool to remove vegetable matter and burrs.

[4] See Stern, *Jour. Chem. Soc.*, 1904, p. 336.

[5] Stahmer's method. Oxycellulose is also likely to be produced in this reaction.

The product obtained in this manner is in the form of a white powder and is very resistant to further hydrolysis by acids and alkalies.

Hydrocellulose may also be prepared in the following manner: Chlorine gas is passed into glacial acetic acid until the solution is perceptibly yellow. Then 5 parts of this acid mixture is heated to 60°–70° C., and thoroughly mixed with 1 part of cotton. In a short time the cotton swells up considerably and becomes viscous. The heating is continued until a sample is found to be completely miscible with water. The product is then washed until neutral and then dried.

Hydrocellulose is to be distinguished from cellulose in that it is colored blue by a solution of zinc chlor-iodide or with a solution of iodine in potassium iodide. Hydrocellulose also reduces Fehling's solution and an ammoniacal solution of silver nitrate, due to the presence of free carbonyl groups in the molecule.

Justin-Mueller states that between the temperatures of 130° C. and 140° C., hydrocellulose begins to turn yellow and form caramel, while oxycellulose scarcely turns yellow at 145° C. to 150° C., and cellulose itself only begins to turn yellow at a temperature of 180° C. This reaction may therefore be employed as a characterisation of hydrocellulose even in the presence of oxycellulose and cellulose.

Hydrocellulose is not to be confused with hydracellulose. The latter contains only water of hydration, whereas the former is a hydrolysed product of cellulose intermediate between normal cellulose and completely hydrolysed cellulose (sugar).

Hydrocellulose is characterised by its reducing power and its solubility in caustic soda solution. Like cellulose itself, hydrocellulose exhibits great affinity for water, giving hydrates of hydrocellulose. The extent of the hydration of hydrocellulose is determined by the degree of hydrolysis; that is to say, the more hydroxyl groups (OH) a cellulose contains, the more water it will combine with.

There is considerable difference in hydration and hydrolysis in the case of cellulose; while cotton may be converted apparently into a hydrated cellulose without structural disintegration, where it is converted into hydrocellulose (by the action of dilute acids) the structure and consequently the strength of the fiber is destroyed. Both hydration and hydrolysis, however, under certain conditions may occur simultaneously. The hydrated celluloses (of which there may be many varying in degree of hydration) are characterised by high hygroscopic moisture, whereas the hydrocelluloses are abnormally low in this respect. Hydrated celluloses, where the original structure of the fiber is retained (mercerised cotton), have high tensile strength, but in hydrated celluloses of an amorphous character (the artificial silks) the tensile strength is low. All hydrated

celluloses are characterised by a diminished resistance to hydrolysis by acids to an extent proportional to their " degree of hydration."

If hydrocellulose (prepared according to Girard) is boiled with dilute caustic soda the insoluble residue loses its reducing properties and shows all the properties of unchanged cellulose. It follows from this fact, in all probability, that hydrocellulose consists of at least two materials, unchanged cellulose and soluble degradation products. This view of the non-homogeneity of hydrocellulose has been confirmed by Netthöfel,[1] and by Hauser and Herzfeld.[2] Netthöfel shows that it is also possible to separate the two parts of hydrocellulose by boiling with Fehling's solution; if the cuprous oxide precipitated on the cellulose by this treatment be dissolved in acid and the residue carefully washed, pure cellulose remains. He also showed by careful microscopic study the complex nature of hydrocellulose and that its largest part still consists of unchanged cellulose.

By far the most important reactions of hydrocellulose are those of the degraded part, that is, ultimately, of dextrose.

(1) So far as reducing power is concerned, this is clear without further comment. If the alkali-soluble part is removed by boiling with caustic soda, the reducing power disappears at the same time.

(2) It is further asserted of hydrocellulose that it decomposes hydriodic acid with liberation of iodine. This phenomenon is explained without trouble by the presence of sugar-like degradation products.

(3) In the same way the explanation is to be found of the yellow coloration of hydrocellulose on heating with dilute alkalics: sugar-like substances show this yellow coloration.

(4) Hydrocellulose gives a good yield of acetic acid when heated under pressure with alkalies. However, both cellulose and sugar-like substances give acetic acid under this treatment, cellulose in considerable amounts, on which account the acetic acid from hydrocellulose may come for the most part from the unchanged cellulose, and for the rest from the degradation products containing sugar.

(5) On oxidation hydrocellulose gives, beside acetic acid, saccharic acid and oxalic acid. Of these two, oxalic acid also results from the oxidation of cellulose. The appearance of saccharic acid may be explained by the presence of sugar-like decom position products in the hydrocellulose.

(6) The same explanation must be claimed for the presence of isosaccharic acid which Tollens obtained when he cooked hydrocellulose with milk of lime.

(7) The fact that hydrocellulose contains one molecule of chemically combined water has previously been regarded as highly characteristic of hydrocellulose, its empirical formula accordingly being $C_6H_{10}O_5H_2O$. Some time ago Schwalbe and also Ost expressed the opinion that this water content of hydrocellluose should be confirmed.

Since it was unlikely from previous knowledge of the nature of hydrocellulose that this view is correct, we must again consider Netthöfel's explanation of the supposed water content:

[1] *Dissertation*, Berlin, 1914.
[2] *Chem. Zeit.*, 1915, p. 689.

We have in hydrocellulose a mixture of unchanged cellulose and sugar-like degradation products, that is, of $C_6H_{10}O_5$ and $C_6H_{12}O_6$. Accordingly the percentage of oxygen and hydrogen in such a mixture must be greater than in pure cellulose with the composition $C_6H_{10}O_5$. From this a molecule of chemically combined water can readily be figured out. The supposed water content comes therefore from the sugar-like degradation products.

The different formulas which have been established for hydrocellulose (by Girard, Büttner and Neuman, and others) can thus be explained: for the greater the amount of sugar-like degradation products in the hydrocellulose, the greater will be the "water content."

So far as the other properties attributed to hydrocellulose are concerned, namely its increased activity toward esterification, hydrolysis under pressure, etc., these are not peculiarities, but are easily explained on the ground that the distorted, disintegrated and pulverised fibers offer to the reagents a larger surface and a more reactive material than the long-fibered cellulose.

Finally, the peculiar behavior of dyestuffs toward hydrocellulose is likewise not to be regarded as characteristic, because here there are numerous contradictions which cannot be explained, since it could never be proved that the material was homogeneous.

6. Hydralcellulose.—This is a product described by Bumcke and Wolffenstein [1] and prepared by the action of hydrogen peroxide on cotton cellulose. It is not a product of oxidation, but one of hydrolysis and is made by steeping cotton in a strong solution of hydrogen peroxide for as long as ninety days. The product is a white powder which shows strong reducing properties towards Fehling's solution and also with an ammoniacal silver solution; it also yields a yellowish-colored hydrazone. The body is apparently an aldehyde, and may also be formed as an intermediate step in the preparation of oxycellulose. When boiled with ten times its quantity of a 10 percent solution of caustic soda, hydralcellulose is converted for the most part into cellulose and a soluble portion which is called "acid cellulose." These reactions, however, need further confirmation, as there is still some doubt as to the identity and existence of these bodies.

7. The Carbonising Process in Relation to Cotton and Vegetable Fibers.—In the carbonising process the material to be treated is impregnated with a boiling solution of sulfuric acid of 2° Bé., squeezed, dried, and then beaten or washed thoroughly to remove the disintegrated cotton fibers or other vegetable cellulose. In another method gaseous hydrochloric acid is allowed to act on the material in place of the sulfuric acid solution. Solutions of certain acidic salts such as magnesium chloride and aluminium chloride are also employed for carbonising. These salts when dried into the fiber liberate free hydrochloric acid which decomposes the vegetable matter. With magnesium chloride it is customary to use a solution of 9° Bé., and with aluminium chloride one of 7° Bé. the material being saturated with one of these solutions and dried at a temperature of about

[1] *Berichte*, 1899, p. 2493.

300° F. After this the material is well washed. The choice of the carbonising agent will largely depend on the character of the goods to be treated and the nature of the dyestuff with which they may be colored.

The carbonising process in relation to cotton and related cellulose, must merely be considered as a study of the destructive action of acids or acid substances on the fiber. As the cotton is completely destroyed and eliminated in the process, its connection with carbonising is really a negative one. The detailed study of the carbonising process relates more to the treatment of wool and shoddy, and consequently the reader is referred to those sections for a fuller consideration of this process. At the present point it has been endeavored to limit the discussion solely to its relation to cotton. It may be well to point out, however, that the term "carbonising of wool" is a misnomer. It is really the cotton that is "carbonised" and not the wool, the latter being left in a practically uninjured condition.

8. Action of Zinc Chloride on Cellulose.—A concentrated solution of zinc chloride will dissolve cellulose on heating and digesting for some time. This solution has been employed industrially for the preparation of cellulose filaments, which are subsequently treated with hydrochloric acid and washed for the purpose of removing the zinc salt; the thread is then carbonised and is employed for the carbon filament of incandescent electric lamps.

The threads for the production of the carbon filaments are prepared by forcing the syrupy solution of cellulose through fine glass orifices into alcohol, whereby the cellulose is precipitated in a continuous thread. The filaments obtained from this source are more homogeneous in composition and possess great elasticity and a very uniform electrical resistance.[1]

The product of cellulose with zinc chloride has also received several other industrial applications; *vulcanised fiber* is prepared by treating paper with a concentrated solution of zinc chloride, and the resulting gelatinous mass is manufactured into various articles, such as blocks, sheets, etc. One part of paper is treated with four parts of zinc chloride solution of 65° to 75° Bé., until the fibers are partially gelatinised, when the sheets are then pressed together into very compact masses. The chief difficulty encountered is the subsequent removal of the zinc salt, which necessitates a very lengthy process of washing. Vulcanised fiber is quite hard, having the consistency of horn; but by the addition of deliquescent substances such as glycerol or glucose a pliable product may be obtained. The material may be rendered water-proof by a further process of nitra-

[1] The introduction of tungsten metal filaments for incandescent lamps during recent years has now almost made the carbon filament lamp obsolete, as the tungsten filament gives a much higher lighting efficiency for the same strength of current.

tion. The solution has also been suggested for use as a thickening agent in calico-printing. It has also been suggested for use in the production of lustra-cellulose or artificial silk but has not met with any success in this field.

Cross and Bevan recommend the following method for preparing this solution of cellulose: 4 to 6 parts of anhydrous zinc chloride are dissolved in 6 to 10 parts of water, and 1 part of bleached cotton is then stirred in until evenly moistened. The mixture is digested for a time at 60° to 80° C., when the cellulose is gelatinised; the solution is completed by heating on a water-bath and stirring from time to time, and replacing the water which evaporates. In this manner a homogeneous syrup is obtained. This solution of cellulose is entirely decomposed by dilution, the cellulose being precipitated as a hydrate in combination with zinc oxide. On washing this precipitate with hydrochloric acid a pure cellulose hydrate is obtained, the quantity recovered being approximately equal to the original cellulose taken. When precipitated by the addition of alcohol, a compound of cellulose and zinc oxide is obtained, with 18 to 25 percent of ZnO, and having the approximate molecular ratio of $2C_6H_{10}O_5 : ZnO$.

According to Wynne and Powell [1] the addition of calcium or magnesium chloride is beneficial. Dreaper and Tompkins [2] recommend the use of basic zinc chloride and calcium chloride. Fremery and Erban [3] recommend that the cotton cellulose be first vigorously treated with oxidising agents previous to solution in the zinc chloride. According to Bronnert [4] the cellulose may be dissolved in a cold solution of zinc chloride by a previous strong hydration of the cotton, such as treatment for one hour with a cold concentrated solution of caustic soda. It is claimed that in this manner a solution may be obtained containing 80 percent and more of cellulose.[5] Zinc chloride dissolved in twice its weight of concentrated hydrochloric acid will also dissolve cotton without heating. The cellulose is not much changed if this solution is rapidly diluted, but on long standing the cellulose is broken down to water-soluble dextrins.[6]

A concentrated solution of zinc chloride in hydrochloric acid dissolves cellulose quite rapidly and in the cold. This latter method is useful in the laboratory for the study of celluloses, but as yet has received no technical application.

The reagent is prepared by dissolving one part of zinc chloride in twice its weight of concentrated hydrochloric acid. If the solution of cellulose

[1] *Eng. Pat.* 16,805 of 1884.
[2] *Eng. Pat.* 17,901 of 1897 and *Ger. Pat.* 113,786.
[3] *Ger. Pat.* 111,313 and *Eng. Pat.* 6,557 of 1899.
[4] See Süvern, *Die Künstliche Seide*, p. 307.
[5] See *Ger. Pat.* 118,836 and *Eng. Pat.* 18,260 of 1899.
[6] See Schwalbe, *Die Chemie die Zellulose*, p. 155.

obtained with this solvent is diluted when fresh, the cellulose will be precipitated unaltered; but if the solution is allowed to stand, the cellulose is rapidly resolved into decomposition products, such as dextrin, etc., which are entirely soluble in water. By means of this solution it has been shown that the cellulose molecule does not contain any unsaturated carbon groups, for it exhibits no absorption of bromine. A solution of a lignocellulose, on the other hand, gives a marked bromine absorption, thus showing evidence of unsaturated carbon groups.

Cellulose is colored a deep violet by a solution of zinc chlor-iodide, and this reagent is employed as a delicate test for the presence of cellulose. The reagent may be best prepared by using 90 parts of a concentrated solution of zinc chloride, adding 6 parts of potassium iodide in 10 parts of water, and iodine until saturated.

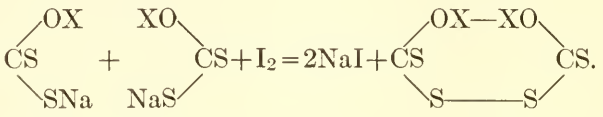
9. Action of Alkalies on Cellulose; Viscose.—When cellulose is treated with concentrated caustic alkalies, it undergoes a change which may be crudely referred to as "mercerisation," whereby a compound known as **alkali-cellulose** is formed, in which the molecular ratio of alkali to cellulose may be given as $C_{12}H_{20}O_{10} : NaOH$. When this body is treated with carbon disulfide, a substance known as **cellulose thiocarbonate** or **xanthate** is formed. This body yields a very viscous solution with water and has been utilised for various technical purposes under the name of **viscose.**

For the preparation of viscose it is best to employ the following molecular proportions of the reagents:

$$C_6H_{10}O_5 : 2NaOH : CS_2 \text{ (with 30 to 40 } H_2O).$$

The reaction is carried out in practice by treating bleached cotton (though other forms of cellulose, such as purified woodpulp, may also be used) with excess of a 15 percent solution of caustic soda, then squeezing out the excess of liquor, but leaving in the fiber about three times its weight of the solution. The mass is then mixed with about 50 percent (on the weight of the cotton) of carbon disulfide, and allowed to stand in a covered vessel for about three hours at the ordinary temperature; after which sufficient water is added to cover the mass, and the hydration allowed to proceed for several hours longer. The mass is then stirred up and a homogeneous solution is obtained which may be diluted to any desired degree. The solution thus prepared has a yellow color, which, however, is due to the presence of various thiocarbonates which occur as by-products in the reaction. By treating the solution with a saturated solution of common salt or with alcohol, pure cellulose thiocarbonate is precipitated as greenish white flocculent mass, which may be redissolved in water, giving a colorless or faintly yellow-colored solution. On the

addition of various metallic salts to this solution, the corresponding xanthates may be precipitated. With iodine a precipitate of dioxythiocarbonate is formed, which may be said to take place in accordance with the following equation (X representing the residue of the cellulose molecule):



Cellulose xanthate undergoes spontaneous decomposition, splitting up into cellulose hydrate, alkali, and carbon disulfide; this cellulose hydrate is also known as *regenerated cellulose*. When this decomposition takes place in solutions containing more than 1 percent of cellulose, a firm jelly of coagulated cellulose is produced of the same volume as the original solution. A solution containing as much as 10 percent of cellulose decomposes to a substantial solid of hydrated cellulose which gives up its water with extreme slowness. The cellulose regenerated in this manner is probably in the "colloidal" form. This substance can also be precipitated from the xanthate solution by the addition of various salts, such as ammonium chloride.

10. Esters of Cellulose.—Alkali cellulose also reacts with benzoyl chloride, with the formation of *cellulose benzoate*.[1] Another ester of cellulose is the *acetate*, which can be made by the action of acetic anhydride on cellulose heated in a sealed tube—regenerated cellulose can also be employed. Cross[2] states that 80 to 90 percent of acetyl groups may be introduced into the cellulose molecule without apparently changing the original properties of the cellulose. According to a recent patent[3] an almost theoretical yield of cellulose acetate may be obtained by conducting the acetylation in the presence of methyl sulfate; the process given being as follows: 30 parts of cotton are treated in a bath with 70 parts of acetic anhydride, 120 parts of glacial acetic acid, and 3 parts of dimethyl sulfate until solution is almost complete. The solution is then filtered and the filtrate is poured into a large quantity of water, whereupon the acetate of cellulose is precipitated.

The acetate of cellulose may be prepared by heating a mixture of hydrocellulose, acetic anhydride, and sulfuric acid to 60°–70° C. The acetate of cellulose so obtained is soluble in ether and chloroform (Lederer). At Sthamer's chemical works (Hamburg) acetate of cellulose is prepared by heating a mixture of hydrocellulose, acetic acid, acetyl chloride, and

[1] See Cross and Bevan, *Cellulose*, p. 32, and *Researches on Cellulose*, p. 34, etc.
[2] *Jour. Soc. Chem. Ind.*, 1904, p. 297.
[3] *Brit. Pat.*, 1905, No. 9998.

sulfuric acid to 65°–70° C. An acetate of cellulose soluble in alcohol and pyridine is obtained by heating a mixture of cellulose, acetic anhydride, and sulfuric acid to 45° C.[1] Miles and Pierce obtain it by heating a mixture of cellulose, acetic anhydride, acetic acid, and sulfuric acid to 70° C. Landsberg substitutes phosphoric acid for sulfuric acid in the preceding mixture. Acetate of cellulose has also been prepared by warming a mixture of cellulose, acetic acid, acetic anhydride, and a mixture of phenol-sodium sulfonate and phenol-sulfonic acid, or of sodium naphtholate and naphthol-sulfonic acid (Little, Walker & Mork). Cellulose may also be acetylised by means of a mixture in nitrobenzene solution of acetyl chloride and chloride of zinc or magnesium, in the presence of pyridine or quinoline (Wohl, Charlottenburg).

Cellulose regenerated from viscose esterifies much more readily with anhydrides and chlorides of acids than does ordinary cellulose. The tetracetate of cellulose in particular is obtained by mixing intimately hydrate of cellulose with a concentrated solution of magnesium acetate, in the proportion of two molecules of the acetate for one molecule of cellulose. To this mixture, which is made homogeneous and dried at 110° C. (230° F.), is added two molecules of acetyl chloride for each molecule of magnesium acetate. The action of acetyl chloride must proceed progressively and with caution, so as to prevent the temperature rising above 30° C. (86° F.). The product is afterward treated with water to remove the magnesium salts; it is then dried and exposed to the action of a solvent to separate the cellulose acetate from the small quantity of uncombined cellulose. This solution is clarified and filtered, and then is evaporated, the residue being the ester in a pure state. The product thus obtained—tetracetate of cellulose—resembles very closely nitrocellulose, but it is distinguished from it by not being explosive; indeed, it is not even very combustible. It dissolves in chloroform, methyl alcohol, epichlorhydrin, ethyl benzoate, glacial acetic acid, nitrobenzene, etc.

These solutions furnish films of perfect transparency and absolute continuity even when they are so thin as to produce interference color effects. They are impermeable to water, and offer great resistance toward the action of reagents. For saponification they must be boiled for several hours with an alcoholic solution of caustic soda; but even then disintegration does not take place, and the film preserves not only its form, but also its transparency.

By varying the conditions of treatment a number of different acetates have been prepared.[2] The *tetracetate* has received a number of com-

[1] Farbenfabriken vorms. Fr. Bayer & Co. of Elberfeld.

[2] Ost (*Zeit. angew. Chemie*, 1919, pp. 66, 76 and 82) has studied quite extensively the formation of cellulose acetates. The triacetate is formed by the action of acetic anhydride and zinc chloride, the other acetates, especially those formed with sulfuric

mercial applications for the production of films and for waterproofing.[1] By the action of nitric acid under varying conditions, a number of *cellulose nitrates* (improperly called nitrocelluloses) have been prepared which have received numerous applications (see *pyroxylin*).[2] Concentrated sulfuric acid reacts with cellulose to form at first a *cellulose sulfate;* this subsequently undergoes decomposition with a consequent hydrolysis of the cellulose molecule and the formation of amyloid. *Aceto-sulfates* of cellulose have been prepared by the joint action of acetic acid, acetic anhydride, and sulfuric acid on cellulose.[3]

For the preparation of what Cross and Bevan term the normal cellulose aceto-sulfate, to which the formula $4(C_6H_7O_2)\cdot(SO_4)\cdot(C_2H_3O_2)_{10}$ is ascribed, 16 grams of dry cotton are stirred for twenty minutes at 30° C. in 100 cc. of a mixture of equal parts of glacial acetic acid and acetic anhydride containing 4.5 percent by weight of sulfuric acid. After standing for one hour, a homogeneous, translucent, and viscous solution is obtained, which is precipitated on being poured into water as a semi-translucent gelatinous hydrate, which is soluble in alcohol. By using less sulfuric acid the product obtained is insoluble in alcohol.

11. Action of Metallic Salts.—Although cellulose is comparatively inert to the majority of chemical reagents, it has a powerful attraction for certain salts held in solution and will absorb them completely. This power of absorption is especially marked toward salts of vanadium, these being completely separated from solutions containing only one part of the salt per trillion.

12. Compound Celluloses.—Besides cellulose itself, there are a number of derived substances which are known as *compound celluloses.* These are classified into three general groups:

(*a*) *Pectocelluloses,* related to pectin compounds of vegetable tissues; represented among the fibers by raw flax; resolved by hydrolysis with alkalies into pectic acid and cellulose. The pectocelluloses are somewhat richer in oxygen than normal cellulose (cotton). When boiled with dilute alkalies they are easily resolved into cellulose, the pectin substances being converted into soluble derivatives. This is the reaction that takes place in the bleaching of linen.

(*b*) *Lignocelluloses,* forming the main constituent of woody tissue and represented among the fibers by jute; resolved by chlorination into chlorinated derivatives of aromatic compounds soluble in alkalies and cellulose. Lignocellulose consists of about 75 percent cellulose and 25 percent of lignin. Jute absorbs iodine, forming an unstable

acid as the catalyst, all show a degradation of the cellulose to a cellulose dextrin, and the existence of a real tetracetate is very doubtful, sulfoacetates and other products being formed.

[1] Noyes (*Kunstoffe,* 1914, pp. 207 and 227) has studied the formation of formic acid esters of cellulose, but formylation is more difficult than acetylation or nitration.

[2] For a thorough and detailed description of the cellulose nitrates and the industries based thereon, consult Worden, *Nitrocellulose Industry,* 2 vols., 1911.

[3] See Cross, Bevan & Briggs, *Berichte,* 1905, p. 1859.

compound. This reaction is employed in the quantitative determination of lignocelluloses in combination with other forms of cellulose. Lignocelluloses also hydrolyse much more readily than normal cellulose.

(*c*) *Adipocelluloses*, forming the epidermis or cuticular tissue of fibers, leaves, cork, bark, etc.; resolved by oxidation with nitric acid into derivatives similar to those of the oxidation of fats and cellulose. The adipocelluloses are cellular rather than fibrous in structure. They contain more carbon and less oxygen than normal cellulose.

Frémy groups the various celluloses and their derived bodies in the following manner, which is based on a chemical classification: (*a*) *celluloses*, including normal cellulose, paracellulose, and metacellulose; (*b*) *vasculose* (identical with lignocellulose); (*c*) *cutose*; (*d*) *pectose*.[1]

[1] The subject of cellulose and its derivatives is a very extensive one and its detailed industrial chemistry is beyond the province of the present volume, which endeavors to limit the consideration of this subject to the bearing it may have on the textile fibers. For further studies on the subject of cellulose the reader is referred to the exhaustive treatises of Cross and Bevan, Schwalbe, Beltzer, Worden, etc., as given in the bibliography at the end of the volume.

CHAPTER XVII

CHEMICAL PROPERTIES OF COTTON

1. Action of Heat.—Cotton itself presents the same general reactions and chemical properties as cellulose. It is capable of standing rather **high temperatures** without decomposition or alteration; though it appears that when cotton is subjected to a temperature of 160° C., whether moist or dry heat, a dehydration of the cellulose takes place, accompanied by a structural disintegration of the fiber. This fact has an important bearing on the singeing, calendering, and other finishing processes where high temperatures are used.

Within the limits of the temperatures to be met with in the usual processes of drying, a dry heat has little or no influence on the substance of the cotton fiber. At 250° C. cotton begins to turn brown; and when **ignited in the air** it burns freely, emitting an odor faintly suggesting acrolein, but without the characteristically empyreumatic odor of burning animal fibers.

When cotton yarn is dried for twelve hours at 70° C. (160° F.) it loses about 5 percent in tensile strength, and also much of its elasticity, becoming harsh and brittle. It rapidly regains its hygroscopic moisture, however, on exposure to the air and recovers its original strength. Heated from 90° to 100° C. (195° to 212° F.) cotton loses about 6 to 8 percent in weight; from 100° to 120° C. about 0.5 percent more. Above 120° C. the loss is very slow, and indicates decomposition; at 180° C. (360° F.) it will have lost about 1 percent more in weight, and the fiber begins to acquire a yellowish color showing the beginning of carbonisation.

When subjected to **dry distillation** cotton is decomposed into methane, ethane, water, methyl alcohol, acetone, acetic acid, carbon, dioxide, pyrocatechol, etc.

The following table gives the results of the dry distillation of cotton (Ramsay and Chorley):[1]

Distillate.	Raw Cotton, Percent.	Bleached Cotton, Percent.	Cotton Cellulose from Viscose, Percent.
Solids and carbon	33	34.44	42.0
Liquids	46	51.11	44.0
Carbon dioxide	11	7.77	7.4
Other gases	10	6.68	6.6

[1] *Jour. Soc. Chem. Ind.*, 1892, p. 872.

The composition of the liquid distillate per 100 parts of cotton is as follows:

Substance.	Raw Cotton, Percent.	Bleached Cotton, Percent.	Cotton Cellulose from Viscose, Percent.
Acetic acid	1.31	2.11	2.00
Methyl alcohol	7.07	10.24	10.24
Tars	12.00	13.33	13.33

The composition of the gaseous distillate is as follows:

Substance.	Raw Cotton. Percent.	Bleached Cotton, Percent.	Cotton Cellulose from Viscose, Percent.
Carbon dioxide	76.90	54.14	80
Oxygen	3.66	8.50	4
Residual gases	19.44	37.36	16

2. Action of Light.—It is a well-known fact that when cotton fabrics are long exposed to the action of light, and especially direct sunlight, a gradual deterioration is the result. Witz [1] showed that oxycellulose was formed from cotton in the presence of air and moisture; Girard, however, claims that in this case it was more probable that hydrocellulose was formed. Witz also exposed a cotton fabric during an entire summer under conditions in which air and moisture were excluded and only light was the active agent. He found the formation of oxycellulose on cloth exposed to blue rays but none on cloth exposed to yellow or red rays. Doree and Dyer [2] made an investigation on the action of ultra-violet light on the strength and durability of cotton fabrics, and found that oxycellulose was formed rather rapidly. It is no doubt the violet and ultra-violet rays in sunlight that cause the destructive action of light on cotton cellulose.

3. Action of Water.—Cotton is unaltered and insoluble in cold and boiling water. Treatment in boiling water for twelve hours appears to increase the dyeing effect of cotton for substantive dyes and to decrease it for basic dyes.[3] This is probably due to a partial hydration of the

[1] *Bull. Soc. Ind. Rouen*, 1883, p. 190.
[2] *Jour. Soc. Dyers & Col.*, 1917, p. 17.
[3] Hübner and Pope, *Jour. Soc. Chem. Ind.*, 1904, p. 404.

cotton cellulose, causing a slight change in chemical properties without alteration in physical form or structure. When cotton is heated for eight hours under pressure at 150° C. (300° F., corresponding to 4.75 atmospheres) it is not apparently affected. By the action of boiling water or steam, however, cotton undergoes certain physical modifications; it becomes plastic, somewhat after the manner of wool, but to a less degree. On this property are based some important effects in finishing, as in calendering, the production of silk finish, beetling, and many others. At 160° C. (320° F., corresponding to 6.15 atmospheres pressure), however, the fiber appears to undergo some alteration. If air is also present the effect is very pronounced at 170° C. (340° F., corresponding to 7.85 atmospheres pressure). Hydrocellulose is apparently formed when cotton is heated with water under a pressure of 20 atmospheres. When cotton is subjected to the action of steam under high pressures the fiber undergoes disintegration, the effect, no doubt, of hydrolytic action. A considerable rise in temperature is noted when cotton is wetted with water. This effect, however, does not appear to be due to chemical action, as the same effect is obtained on wetting finely divided inert solids. Masson[1] has made a detailed study of the conditions which give rise to these phenomena. Martini[2] also gives a study of this effect. According to Masson the action is due to a distillation effect, whereas Martini considers that the liquids are absorbed by the solids, passing into the solid state themselves.[3]

Cotton becomes yellow when exposed to **steam,** and it has actually been proposed to impart to white cotton the appearance of Egyptian varieties by steaming under 1 to 1.5 atmospheres pressure for twenty-five to thirty seconds.[4] The yellowing is not due to the fatty constituents of the cotton, and, in fact, F. Erban has found that the phenomenon is intensified if the fat has been extracted.[5] The " gums " in the cotton may contribute to the process but, on the whole, fully scoured cotton is as liable to become yellow as raw cotton. The subject has been studied by Freiberger,[6] who came to the following conclusions: (*a*) Bleached fabrics show the strongest discoloration, those bleached cold being more susceptible than fabrics bleached warm; (*b*) fabrics bleached warm with sodium hypochlorite containing an excess of sodium carbonate are less subject to yellowing; (*c*) oxycellulose becomes quite one hundred times as dark as cellulose on steaming, but hydrocellulose is less affected than cellulose.

[1] *Proc. Roy. Soc.*, vol. 74, p. 230.
[2] *Phil. Mag.*, vol. 47, p. 329.
[3] See also *Phil. Mag.*, vol. 50, p. 618.
[4] *Text. Mer.*, 1914, Feb.
[5] *Färber-Zeit.*, 1912, p. 370.
[6] *Färber-Zeit.*, 1917, pp. 221, 235, 249.

The main cause of the yellowing of cotton on steaming is therefore the presence of oxycellulose.

Scheurer [1] has made a study of the action of prolonged steaming on cotton fabrics. He used both gray cloth and cloth which had been boiled-out for bleaching, and steamed the samples at a temperature of 99° to 100° C. for varying periods of time with the following results as to tensile strength:

	Gray Cloth.		Boiled-out.	
	Warp.	Filling.	Warp.	Filling.
Original cloth	100	100	100	100
Steamed 60 hours	82	76	83	90
120 "	72	49	70	69
180 "	60	40	59	58
240 "	51	37	53	50
300 "	39	32	47	34
360 "	31	30	41	34
420 "	27	19	31	25
480 "	21	19	20	19
540 "	21	13	14	17

It would seem, therefore, that the gray and the white pieces are affected in about the same way by the steaming. As the steam is always charged with a certain amount of air, the effect is really due to the joint action of steam, temperature, and air. In tests on the comparison of steaming of wool and cotton it was found that four hundred and twenty hours of steaming tendered cotton 75 percent and sixty hours of steaming tendered wool 75 percent; therefore, it was concluded that the resistance of cotton to steaming is about seven times greater than that of wool.

The action of frost or ice on cotton has been investigated by Rothwell.[2] Two pieces of bleached cloth, one of good quality and one of poor quality, were placed in water for ten minutes, then taken out and, without squeezing, hung up in a freezing atmosphere. The cloth became quite stiff in three minutes, and though the temperature never increased beyond 3° C. for three hours, the ice had completely evaporated at the end of that time, leaving the cloth perfectly dry. On testing along with the original cloth no loss in strength was observed. Even after repeating the freezing operation four times the strength of both qualities of cloth was found to be

[1] *Bull. Soc. Ind. Mulh.*, 1893.
[2] *Jour. Soc. Dyers & Col.*, 1892, p. 153.

equal to the original. From this it is evident that cloth frozen in full open width is not tendered.

The following table shows the effect of moisture on the strength and elasticity of cotton and linen yarns,[1] the figures being the average of twenty tests in each case:

Material.	Strength, Ounces.		Elasticity, Percent.	
	Dry.	Moist.	Dry.	Moist.
20's cotton yarn, gray	25.5	28.1	3.1	3.9
20's cotton yarn, bleached	24.7	24.8	3.7	4.2
40's cotton yarn, gray (American)	9.1	10.6	2.4	2.9
40's cotton yarn, gray (Egyptian)	11.2	11.3	2.5	3.1
40/2 cotton yarn, gray (hard twist)	24.2	27.3	2.4	3.6
40/2 cotton yarn, bleached (hard twist)	25.6	23.3	3.9	3.1
25's carded flax tow yarn, gray	54.2	63.3	0.8	1.4
25's card flax tow yarn, bleached	26.1	46.2	0.7	1.4
30's flax line yarn, gray	75.2	75.7	0.9	1.4
30's flax line yarn, bleached	54.0	60.0	1.0	1.4

4. Action of Cuprammonium Solution.—Like cellulose itself, cotton is dissolved by **Schweitzer's reagent,** though under ordinary conditions its solution is a rather slow process. In order to dissolve cotton most effectively in ammoniacal copper oxide, it is recommended to treat the raw cotton with a strong solution of caustic soda until the fibers swell up and become translucent; squeeze out the excess of liquid, and wash the cotton with strong ammonia water; then treat with the solution of ammoniacal copper oxide and the cotton will be found to dissolve quite rapidly. This solution may furthermore be filtered and diluted with water. The use of this solution for the production of artificial silk filaments is now practiced on a large commercial scale. It is also used for the preparation of artificial fabrics, such as lace and tulle. This reaction is also utilised in the preparation of a fabric known as *Willesden canvas;* the cotton fabric is passed through a solution of ammoniacal copper oxide, whereby the surface becomes coated with a film of gelatinised cellulose containing a considerable amount of copper oxide. On subsequent hot pressing this film is fixed on the surface of the material as a substantial coating, which is said to make the canvas waterproof and render it unaffected by mildew and insects.

If the solution of cotton in the cuprammonium reagent is exposed to the light for some time, a precipitate of cellulose and copper hydrated oxide will form. If the latter is dissolved away with hydrochloric acid

[1] *Oester. Woll. u. Leinen-Ind.*

the cellulose is left in the form of needlelike crystals (Gilson); but according to Schwalbe, cotton cellulose has never yet been noticed in this form, as all recent observations show it to exist in the colloidal form.

5. Action of Acids.—With **mineral acids** cotton exhibits practically the same general reactions as pure cellulose. **Concentrated sulfuric acid** produces amyloid in the manner previously mentioned, and this fact is utilised in the preparation of what is known as *vegetable parchment.* Unsized paper is rapidly passed through concentrated sulfuric acid, then thoroughly washed and dried. The effect of this treatment is to cause the formation on the surface of the paper of a layer of gelatinous amyloid, which on subsequent pressing and drying gives a tough membranous surface to the paper resembling true parchment. This renders the paper grease-proof and water-proof, and increases its tensile strength considerably.

Mercer (in 1844) appears to have been the first to discover the effect of concentrated sulfuric acid on cotton; in fact this reaction was developed at the same time as that of strong solutions of caustic soda on cotton. Mercer pointed out that the action of the concentrated sulfuric acid was very similar in its effect to that of the strong alkali in that the fiber swelled somewhat, and the cotton showed an increase in strength and an increased affinity for many dyes. The action of the strong acid must be very brief, otherwise the cotton will be dissolved with the formation of sulfuric acid esters. This matter will be further discussed under the subject of mercerisation.

Artificial horse-hair has been prepared in a similar manner from certain Mexican grasses. These latter are steeped for a short time in concentrated sulfuric acid, and become parchmentised thereby, so that on being subsequently washed and combed they assume an appearance very much resembling horse-hair, and are said to possess even greater elasticity than horse-hair itself. In place of strong sulfuric acid a solution of zinc chloride may be used with similar results. Amyloid appears also to be a product of natural plant growth, as its presence has been detected in the walls of vegetable cells; it may be recognised by giving a blue color with iodine. The parchmentising action of strong sulfuric acid on cotton has become a very important commercial process in connection with mercerising for the production of a permanent stiff finish on the fabric. Its consideration will be taken up under the subject of mercerising.

Under proper conditions of treatment concentrated mineral acids have a mercerising or hydrating action on cotton. Sulfuric acid at the ordinary temperature begins to exert a mercerising effect at a strength of 35° Bé. Acid of 49° to 55° Bé. acts much in the same manner as caustic soda; the fiber becomes mercerised and possesses an increased affinity for dyestuffs, and acquires an increased luster and strength. The same is also true of

concentrated solutions of phosphoric acid (59° Bé.). If the action, however, of the acids is at all prolonged, complete hydrolysis and destruction of the fiber take place. By the prolonged action of concentrated sulfuric acid (over 50 percent) on cotton, the fiber is dissolved with the formation of a sulfuric acid ester of cellulose. Langhaus [1] describes this method for the preparation of artificial silk. He also describes the solution of cotton in phospho-sulfuric acid.[2] Neither of these processes, however, seem to have met with any commercial success.

Very **dilute solutions of sulfuric acid** especially in the cold, have no appreciable action on cotton. But if the fiber is impregnated with such a solution and then allowed to dry it becomes tendered; this is owing to the gradual concentration of the acid on drying, and hydrolysis of the fiber. According to Bowman, the acid acts as a catalytic agent, probably forming at first an unstable compound with the cellulose which is decomposed by water and air into hydrocellulose, thus liberating the acid again in the free state to combine with a fresh portion of the cellulose. Jentgen [3] also supports this view of the reaction. Elevated temperatures also cause the dilute acid to attach the fiber much more quickly and severely than otherwise.[4] According to Büttner and Neuman [5] when cotton is treated with dilute sulfuric acid of sp. gr. 1.45–1.53 a mixture is obtained consisting probably of hydrocellulose and oxycellulose with more or less unchanged cellulose.

The action of dilute mineral acids on cotton seems to be one of hydrolysis, whereby a molecular change occurs in the fiber substance. This hydrolytic action is supposed to result in the formation of hydrocellulose, having the formula $2C_6H_{10}O_5 \cdot H_2O$. The action of the acid no doubt takes place in several phases, as shown by the subsequent acetylation of the products. It is quite certain that between the body $C_{12}H_{20}O_{10} \cdot H_2O$, which should correspond to the hydrocellulose of Girard, and ordinary cellulose, $C_{12}H_{20}O_{10}$, there exists a series of hydrocelluloses comprised under the general formula, $(C_6H_{10}O_5)_x \cdot H_2O$. Acetic acid has but small hydrolytic action, and consequently has little effect on cotton.

Knecht and Thompson [6] have made a thorough study of the action of dilute sulfuric acid on cotton and they come to the conclusion that the action that takes place is of a twofold nature. The cotton cellulose

[1] *Ger. Pat.* 75,572.

[2] *Ger. Pat.* 82,857.

[3] *Zeit. f. angew. Chem.*, 1910, p. 1537.

[4] It would seem that Köber, in 1852, was the first to recognise the action of dilute mineral acids on cotton and to apply it industrially in the treatment of half-woolen rags for the purpose of destroying the cotton and thus permitting of the recovery of the more valuable wool (see also sections relating to carbonising).

[5] *Zeit. ang. Chem.*, 1908, p. 2609.

[6] *Jour. Soc. Dyers & Col.*, 1921, p. 272.

is partly hydrolysed, which results in a reduction of the strength of the fiber, and there is also a fixation of some of the acid which behaves as a mordant for some of the basic colors. By soaking cotton in a $\frac{1}{10}$ percent solution of sulfuric acid and drying, both of the actions take place, the product being tendered and exhibiting a great attraction for Methylene Blue, Rhodamine B, Crystal Violet, and other basic dyes, even after prolonged washing with water and alkali. It has, on the other hand, very little affinity for direct colors, notably Diamine Sky Blue. It has been indicated by other investigators that the increased affinity for Methylene Blue does not depend on the degree of tendering. Thus, if cotton is boiled for an hour with sulfuric acid of $\frac{1}{2}$ percent strength, while the strength of the fiber is seriously impaired, its affinity for Methylene Blue is not increased but slightly diminished. It would seem, according to Knecht, that cotton cellulose that has been modified by treatment with dilute sulfuric acid is not oxidised cellulose, but contains fixed sulfur which is not removed by washing with boiling water and alkali. Also it is pointed out that oxidised cellulose and the sulfuric acid hydrolysed cellulose may be distinguished by boiling with weak alkali and then dyeing with a direct color.

In all dyeing and bleaching operations where the use of acid may be required, the above facts should always be borne in mind; the temperature of the acid baths should be not above 70° F., and the acid strength should not be more than 2 percent. Where higher temperatures are necessary, organic acids should be substituted for mineral acids wherever possible. Acetic and formic acids, for instance, are often used.

Whenever cotton is treated with acid solutions or with salts of an acid nature, or which are liable to decompose with liberation of acid, all of the acid should be removed from the fiber or properly neutralised before drying, else the material will be tendered and probably ruined. The action of dilute acid on cotton is probably a hydrolysis of the cellulose molecule, with the formation of hydrocellulose causing a structural disorganisation of the fiber.

The tendering of cotton dyed with sulfur colors, which is sometimes noticed, is due to the presence of free sulfuric acid arising from the oxidation of the dyestuff. This liberation of sulfuric acid is accelerated by exposure to heat. Holden [1] by exposing samples of cotton dyed with various sulfur dyestuffs to a temperature of 120° C. for twenty hours, found that the material lost in strength from 39 to 78 percent, and the amount of free sulfuric acid liberated varied from 0.027 to 0.078 percent on the weight of the cotton. Methods for preventing this tendering effect of the sulfur dyes rely for their efficiency either on assisting the oxidation of the dyestuff (as in the treatment with bichromates), or on after-treating

[1] *Jour. Soc. Dyers & Col.*, 1910, p. 76.

the dyed material with salts capable of neutralising free mineral acids. These latter compounds usually have the disadvantage of being soluble in water. Holden recommends the precipitation of calcium tannate on the dyed material.

Hydrochloric acid has an effect similar to sulfuric acid, and the same remarks concerning the use of this latter acid in connection with cotton also hold true for the former. Dry hydrochloric acid gas does not seem to act on cotton at all, but if moisture is present the decomposition is very rapid. On this account it is now used quite extensively in the carbonising of wool-cotton rags, the latter being heated at 212° F. with moist hydrochloric acid gas in a special form of apparatus.

According to Knecht [1] if cotton is steeped in hydrochloric acid of 37° Tw. the fiber will shrink and also show a greatly increased affinity for substantive dyestuffs, while at the same time the feel and the tensile strength of the cotton are not injured. The treated cotton does not show any increased affinity towards tannic acid or the basic dyestuffs. The shrinkage of cotton yarn is about 4 percent when treated with hydrochloric of 37° Tw. and about 8 percent with acid of 38° Tw. With hydrochloric acid of 40° Tw. the cotton is badly injured, becoming tendered, harsh and brittle.

According to W. A. Lawrance,[2] when cotton yarn is treated with very dilute acid and dried, charring does not take place, but the fibers are more or less affected by such a treatment, as is shown by the loss of tensile strength. The microscope failed to reveal any structural changes worth noting, and where the loss in strength was less than 20 percent negative results were obtained when tests for hydrocellulose were made with zinc chlor-iodide after freeing the yarn from the last traces of acid.

The percentage decrease in tensile strength produced by dilute acids on 3/8's cotton yarn, under conditions described, is tabulated in the following tables:

Cotton Yarn Treated with Acid at 20° C. for Sixteen Hours

Temperature of Drying.	Concentration of the Acid.							
	1/5N	1/7N	1/10N	1/25N	1/50N	1/100N	1/150N	1/200N
20° C.	70	64	44	20	9	2	0	0
40° C.	89	83	63	42	26	6	3	0
60° C.	94	92	86	71	49	19	8	4
80° C.	97	96	94	89	80	59	33	27
100° C.	99	98	96	92	88	67	51	40

[1] *Jour. Soc. Dyers & Col.*, 1915, p 8. [2] *Canadian Chemical Journal*, 1922.

COTTON YARN TREATED WITH ACID AT 38°-40° C. FOR ONE HOUR

Temperature of Drying.	Concentration of the Acid.							
	1/5N	1/7N	1/10N	1/25N	1/50N	1/100N	1/150N	1/200N
20° C.	75	70	47	29	11	6	4	0
40° C.	92	87	72	56	32	9	6	4
60° C.	95	94	88	75	55	22	12	8
80° C.	98	97	95	90	83	62	38	33
100° C.	99	99	97	93	90	72	56	45

COTTON YARN TREATED WITH ACID AT 58°-60° C. FOR ONE HOUR

Temperature of Drying.	Concentration of the Acid.							
	1/5N	1/7N	1/10N	1/25N	1/50N	1/100N	1/150N	1/200N
20° C.	79	73	52	30	13	8	6	5
40° C.	93	89	75	59	40	14	10	7
60° C.	96	95	89	76	58	25	15	10
80° C.	99	98	96	91	85	70	44	37
100° C.	100	100	97	94	92	78	60	49

COTTON YARN TREATED WITH ACID AT 100° C. FOR ONE HOUR

Temperature of Drying.	Concentration of the Acid.							
	1/5N	1/7N	1/10N	1/25N	1/50N	1/100N	1/150N	1/200N
20° C.	88	84	70	37	20	11	9	7
40° C.	96	94	88	65	50	17	13	10
60° C.	98	97	91	81	68	28	19	15
80° C.	100	99	97	93	88	77	60	45
100° C.	100	100	98	96	95	84	66	56

These results clearly demonstrate the sensitivity of cotton to very dilute acids. It is presumed that sulfuric acid was used.

It will be observed from the data obtained that the temperature of drying cotton after contact with very dilute inorganic acid is of more importance than the concentration of the acid within certain limits. For instance, cotton yarn treated with 1/100N acid at 20° C. and dried at

that temperature lost but 2 percent of its strength, but when dried at 100° C., lost 67 percent, which is approximately the loss produced by 1 5N acid and drying at 20° C. Weak acid solutions, with a concentration less than 1 50N have little immediate effect upon cotton, provided the drying takes place at room temperature, but will tender more or less with age.

Cohen [1] has studied the effect of dilute solutions of acids on cotton under varying conditions, and the results are shown in the following table:

Strength of Acid Used, Percent.	Copper Equivalent.			
	Cotton Boiled in HCl for One Hour.	Cotton Boiled in H_2SO_4 for One Hour.	Cotton Soaked in Cold HCl, Dried and Heated at 120° C. for 10 Minutes.	Cotton Soaked in Cold H_2SO_4, Dried and Heated at 120° C. for 10 Minutes.
1	3.256	2.537		
$\frac{1}{2}$	2.224	1.822		
$\frac{1}{4}$	1.628	1.325		
$\frac{1}{8}$	1.192	0.994	.....	1.325
$\frac{1}{16}$	0.867	0.773	.....	0.994
$\frac{1}{32}$	0.760	0.608	.....	0.805
$\frac{1}{64}$	0.651	Same as for distilled water	.....	0.663
1 100	.....	.....	0.899	
1 128	0.597	.....	.....	0.568
1 150	Same as for distilled water	.....	0.757	
1 200	.....	.....	0.663	
1 400	.....	.....	0.568	
Distilled water	0.541	0.541	0.531	0.531

These results indicate that if cotton is boiled in hydrochloric acid for one hour the cotton will be affected when the strength of the acid is 1 128 percent and upward. Sulfuric acid under the same conditions, affects the cotton when the strength is 1 32 percent and upward. If any solution of acid weaker than these strengths is employed the cotton is not affected. In each case hydrochloric acid has a greater affect on the cotton than has sulfuric acid. It will also be seen that by heating the cotton soaked with the dilute solution of acid the effect is obtained with a much weaker solution. Cohen also gives the following table showing

[1] *Jour. Soc. Dyers & Col.*, 1915, p. 162.

the relation between the copper equivalents and the tensile strengths of cotton yarns after acid treatment:

Cotton Boiled One Hour with H_2SO_4, Percent.	Tensile Strength of the Yarn, Grams.	Copper Equivalent.
1	220	2.537
$\frac{1}{2}$	340	1.822
$\frac{1}{4}$	390	1.325
$\frac{1}{8}$	440	0.994
$\frac{1}{16}$	495	0.773
$\frac{1}{32}$	535	0.608
Distilled water	575	0.541

6. Testing Cotton Fabrics for Acid.—The usual method of testing for the presence of acid in a cotton fabric is by simply pressing a piece of litmus (blue) paper against the moistened cotton, or the cloth is boiled with water and the extract is tested with litmus or Methyl Orange. To estimate the quantity of acid the extract may be titrated with a decinormal caustic soda solution. It is pointed out, however, by Coward and Wigley [1] that these tests are not satisfactory as cotton exhibits a preferential attraction for the basic constituent of a neutral salt in aqueous solution. In consequence the British Engineering Standards Association specify that in determining the acidity or alkalinity of aeroplane fabric the aqueous extract should be titrated in the absence of the fabric. This, however, does not give the true amount of acid or alkali originally present in the fabric. It has been shown by Zänker and Schnabel [2] that cotton retains absorbed sulfuric acid with such tenacity as to introduce considerable errors into the estimation of small amounts of that acid by titration of the aqueous extract of the cloth. Higgins [3] has also met with the same difficulty. The best indicator for testing the acidity of cloth is perhaps Methyl Red, which gives a pink or red color with acid and yellow with alkali and is very sensitive. A saturated solution of Methyl Red in water gives a bright red color when spotted on cloth containing 0.005 percent of acid and a bright yellow color with 0.005 percent of alkali in cloth. This indicator, therefore, is excellent for ascertaining if a cloth is well-washed commercially. Litmus paper only gives a slight color change with 0.01 percent of acid or alkali.

The following table by Coward and Wigley shows the proportion of

[1] *Jour. Text. Inst.*, 1922, p. 121.
[2] *Färb. Zeit.*, 1913, p. 282.
[3] *Jour. Soc. Dyers & Col.*, 1918, p. 35.

acid retained by bleached cotton cloth after twice extracting with boiling water:

Acid Added to Cloth (Grams H_2SO_4 per 100 Grams Cloth).	Acid Extracted from Cloth.	Acid Remaining in Cloth.
0.008	0.000	0.008
0.020	0.006	0.014
0.029	0.007	0.022
0.061	0.018	0.043
0.100	0.050	0.050
0.210	0.165	0.045

It was further shown that acidimetry (correct to 0.01 percent hydrochloric or sulfuric acid) and alkalimetry (correct to 0.02 percent NaOH present as Na_2CO_3) of bleached cotton cloth can be accurately carried out by titrations with N 50 solutions, at the boil in the presence of the fabric, with phenolphthalein as indicator, if the following procedure is employed:[1] 100 cc. of distilled water are introduced into an Erlenmeyer flask brought to boil, 1 cc. of 0.5 percent phenolphthalein solution (in alcohol) is added and titrated with N 50 NaOH until a faint color permanent for ten minutes is obtained. Then add 3 grams of the cloth to be tested and boil for a few minutes. The liquid is then titrated with N 50 NaOH until the color remains permanent for ten minutes.

Colored indicators of suitable strength may be used for the approximate estimation of acidity or alkalinity in cotton cloth by spotting on the fabric, as follows:

Indicator.	Acidity or Alkalinity.	Color.
Thymol Blue	0.16 percent H_2SO_4	Purple
Methyl Orange	0.10–0.16 percent H_2SO_4	Yellow-red
Lacmoid	0.06 percent H_2SO_4	Red
KI–KIO_3 starch	0.01 percent H_2SO_4	Blue
Methyl Red	0.005 percent H_2SO_4	Red
Methyl Red	0.005 percent NaOH	Yellow
Brom Thymol Blue	0.02 percent NaOH	Green
Phenolphthalein	0.12 percent NaOH	Pink

7. Action of Nitric Acid.—While dilute solutions of nitric acid have an effect on cotton similar to other mineral acids, strong nitric acid has a somewhat different action. It completely decomposes cotton, in common

[1] McBain, *Jour. Chem. Soc.* (*Brit.*), 1912, p. 814.

with other forms of cellulose, oxidising it to various products among which is oxalic acid. When boiled with moderately concentrated nitric acid cotton is converted into **oxycellulose**, a structureless, friable substance possessing a great affinity for basic dyestuffs. When mixed with concentrated sulfuric acid, however, the action of nitric acid on cotton is totally different, the cellulose being converted into a nitrated body, though the physical appearance of the fiber is not appreciably altered. Bronnert [1] states that nitration of the cotton fiber, even to the extent of introducing 80 percent of nitro groups, does not appreciably alter the visible structure or breaking strain of the thread. The exact nature of the nitrated compound will depend on the conditions of treatment.

Several nitrated celluloses are known and possess commercial importance; they are classified under the general name of **pyroxylins**. Guncotton, a hexanitrated cellulose, is the most highly nitrated product, and is used as a basis of many explosives. Soluble pyroxlin is a trinitrated cellulose; its solution in a mixture of alcohol and ether is called **collodion** and is employed in surgery and photography. Another derivative, supposed to be a tetranitrated cellulose, is also soluble in ether-alcohol and its solution has been utilised for the production of artificial silk filaments. By dissolving nitrated cellulose in molten camphor a substance known as *celluloid* is formed.

The action of nitric acid on cotton fabrics appears to be a peculiar one. The following observations in this respect have been recorded by Knecht: Bleached calico steeped for fifteen minutes in pure nitric acid at 80° Tw., washed and dried, showed a considerable contraction, amounting to about 24 percent; the tensile strength also increased 78 percent. Unbleached yarn, treated in the same manner, also showed a considerable increase of tensile strength, and a proportional contraction in length. Weaker acids did not show these results, the fiber being tendered instead of being strengthened. Analysis proved that 7.7 percent of nitrogen was present, showing that about two molecules of the acid had combined with the cotton. The shrinkage, gain in strength, microscopical appearance, etc., of the treated material, all go to show that in addition to the nitration a mercerising effect has been produced. This appears in the fact that the material exhibits a strongly increased affinity for many dyestuffs, especially the direct cotton colors and some of the acid dyes; while by reason of its not showing any increased affinity for the basic colors there is proof that oxycellulose has not been produced. This action of strong nitric acid on cellulose has been utilised for the preparation of toughened filter-papers which are required to stand high fluid pressures. The filter-paper is immersed in concentrated nitric acid for a brief period and then well washed.

[1] *Rev. Gen. Mat. Col.*, 1900.

The nitration of cotton yarn has been employed for the purpose of obtaining a product that will not dye with direct cotton colors though dyeing rather well with basic colors.[1] The yarn to be treated should be free from chlorine and as dry as possible, and also cold. An acid mixture is prepared in a cast-iron tank with 3 parts of sulfuric acid (168° Tw.) and 1 part of nitric acid (103° Tw.). The mixed acid will contain 21.5 to 22.5 percent of nitric acid, 72 to 73 percent of sulfuric acid and 5 to 6 percent of water. The acid mixture is cooled to 10° C. and then 2 lbs. of the yarn are steeped for one hour in 80 lbs. of the acid. The yarn is then lifted, the excess of acid is squeezed out, and then hydroextracted. The yarn is then brought in small quantities, and as quickly as possible, into a relatively large amount of water to prevent heating. If the yarn is properly submerged the strength of the cotton will not be impaired, while the length of the skein and the texture of the fiber will not be altered. The yarn is then washed in warm water and finally boiled in a dilute solution of soda ash until all trace of acid is removed. The nitrated product obtained in this manner is a hexanitrate and is described as perfectly safe, igniting only when a temperature of 180° C. is reached. By weaving cotton yarn prepared in this manner with ordinary cotton yarn or mercerised yarn, and then dyeing with suitable direct cotton dyes, remarkable two-color effects may be obtained, or the treated cotton may be left practically undyed.

If nitrated cotton be examined under the microscope, a considerable alteration in its appearance will be observed. The fibers have a much thicker cell-wall, and are consequently stiffer than those of ordinary cotton. The lumen has either vanished entirely or become very much contracted, and this appears to be due to the swelling of the cell-walls. In the walls of the fiber there will also be noticed numerous fractures or cracks which often assume a spiral shape. The nitration has evidently rendered the fiber much more brittle and has decreased its elasticity.

Hoepfner has prepared porous acid-proof fabrics to be employed for filtering purposes in electrolytic work by using cotton yarn which has been nitrated. The latter can be woven along with asbestos, glass, or other mineral fibers in the making of the fabric. According to Claessen acid-proof filter cloths may be prepared by first immersing the cloth in cold nitric acid of 40°–50° Bé., then in concentrated sulfuric acid of 60° Bé., finally washing with water until neutral. By this means a superficial nitration only is effected.[2] F. Bayer & Co.[3] state that completely nitrated cloth may be produced by immersion first in nitric and then in sulfuric acid and that the cloth so prepared is superior in quality and strength

[1] Schneider, *Jour. Soc. Dyers & Col.*, 1907, p. 78.
[2] See *Zeit. ang. Chem.*, 1906, p 317.
[3] See *U. S Pat.* 850,266 of 1908.

to that formed from weaving threads made from nitrocellulose solutions, being nearly twice as strong and more resistant to acids and chlorine while at the same time being open and porous. To produce solid cloths which are acid-proof, Bachrach [1] recommends the addition of graphite or bitumen. It is said that 10 percent of either of these will produce a cloth which will successfully resist long contact with corrosive chemicals. Nitrocellulose may be blended with the graphite or bitumen by use of an acid-resisting solvent known as "picamer" [2] which will dissolve nitrate of cellulose. Picamer is obtained by fractionating wood tar distillate with chromic acid or alkaline potassium bichromate.

A process for giving cotton a wool-like character by treatment with nitric acid is described by C. Schwartz.[3] It has been found that a wool-like character may be imparted to cotton or other vegetable fabrics by treating them at the ordinary temperature with a solution of nitric acid of over 65 percent strength, and then washing out the acid. The textile material, in the form of fabric, or yarn, for example, is steeped in a large excess of concentrated nitric acid, in which it floats freely without tension, until the reaction is terminated; then it is squeezed or dried out and washed. The time of contact depends upon the concentration of the acid and the quality of the textile material, especially its porosity and absorbent capacity. For example, one minute will be sufficient soaking for ordinary plain fabrics, in 75 percent nitric acid; two minutes for ordinary calicos in 72 percent acid; five minutes for fine Egyptian cotton batistes in 65 percent acid. This treatment in nitric acid may be prolonged up to five, ten or thirty minutes respectively, without harm as to the final result, on condition that the temperature does not exceed 68° F.; this fact is of great importance in manufacture on a large scale, where it is always necessary to take account of the possibility of stoppages or other causes bringing the apparatus to a standstill for a time. For practical reasons, the temperature of the acid is maintained at a comparatively low temperature to avoid the evolution of acid vapors, but it is possible to reach 77° F. without risk to the material under treatment. With nitric acid of a concentration between 65 percent and 75 percent, it is possible without inconvenience and at the ordinary temperature, to allow the action of the nitric acid upon the fiber to be prolonged. When, on the other hand, this concentration limit of 75 percent is exceeded, it is necessary to insure that the nitric acid acts upon the fiber only for a very short time, some few minutes.[4]

[1] *U. S. Pat.* 692,102 of 1902.

[2] Greening, *Brit. Pat.* 22,019 of 1894.

[3] *U. S. Pat.* 1,384,677.

[4] A new method which is said to be the basis of an important commercial process is described by J. E. Pollak in *British Patent* 167,864. It has for its purpose the con-

The following are descriptions of the principal nitrated products of cotton cellulose. In the formulas given the cellulose unit group is taken as $C_{12}H_{20}O_{10}$.

Cellulose hexanitrate, or guncotton, $C_{12}H_{14}O_4(NO_3)_6$, is made by the use of 3 parts nitric acid of sp. gr. 1.5 and 1 part sulfuric acid of sp. gr. 1.84. The cotton is immersed in this mixture for twenty-four hours at a temperature not above 10° C.; 100 parts of cellulose yield about 175 parts of the nitrate. This nitrate is insoluble in alcohol, ether, or in mixtures of both, in glacial acetic acid, or methyl alcohol; slowly soluble in acetone. Ordinary guncotton may contain as much as 12 percent of nitrates soluble in ether-alcohol mixture.

Cellulose pentanitrate, $C_{12}H_{15}O_5(NO_3)_5$, is prepared by dissolving guncotton (the hexanitrate) in nitric acid at 80° to 90° C., and precipitating by the addition of sulfuric acid after cooling to 0° C. The precipitate consists of the pentanitrate, and is purified by washing with water, then with alcohol, dissolving in ether-alcohol, and reprecipitating with water. The pentanitrate is insoluble in alcohol, is slightly soluble in acetic acid, and readily so in ether-alcohol; by treatment with strong caustic potash it is converted into the dinitrate.

Cellulose tetra- and *trinitrates* (collodion pyroxylin) are formed simultaneously when cotton is treated with a more dilute acid and at higher temperatures, and for a shorter time than in the preparation of the hexanitrate. As these two nitrates are soluble to the same extent in ether-alcohol, acetic ether, and methyl alcohol, it is not possible to separate them. When treated with a mixture of concentrated nitric and sulfuric acids, they are both converted into penta- and hexanitrates; caustic potash and ammonia convert them into the dinitrate.

Cellulose dinitrate, $C_{18}H_{13}O_8(NO_3)_2$, is formed through a partial saponification of the higher nitrates by the action of caustic potash, and also by the action of hot dilute nitric acid on cellulose. The dinitrate is very soluble in ether-alcohol, acetic ether, and in absolute alcohol.

version of the cotton fiber into material which is of a transparent nature while at the same time it acquires a wool-like character. The operation is really based on the production of nitrated cellulose or collodion right on the fabric, and is carried out by treating the cloth for a few seconds with a mixture of an equal volume each of sulfuric acid (134° Tw.) and nitric acid (78° Tw.) cooled to a temperature of 32° F. or lower. The fabrics are then washed thoroughly and dried on a stenter frame. The strength of the nitrifying acid mixture may be varied according to whether a wool-like or a transparent effect is desired.

The application of such a corrosive acid mixture to a cotton fabric would be regarded with dismay by most textile chemists, and if carried out in the simple manner outlined would no doubt be attended with a complete destruction of the fiber. But that it is quite possible to regulate and control the chemical action of this acid mixture on cotton is evidenced by the successful commercial application of concentrated sulfuric acid solutions to cotton in the production of the so-called *Swiss Finish*. The application of the nitrifying acid mixture must be carried out in suitable machines so adjusted as to leave the fiber in contact with the acid for only a prescribed short space of time, and then the removal of the acid mixture must be so conducted as to prevent injury to the goods. The patent simply describes the mere outline of the process and there are many points largely of a mechanical nature which would have to be thoroughly perfected in order that such a treatment might be conducted in a successful commercial manner.

Vielle has studied the nitration of cotton with different concentrations of acid with the following results:

Density of Nitric Acid.	Product Obtained.
1.502 1.497	Structural features of cotton preserved; soluble in acetic ether; not in ether alcohol: $C_{24}H_{20}(NO_3H)_{10}O_{10}$.
1.496 1.492 1.490	Appearances unchanged; soluble in ether-alcohol; collodion cotton: $C_{24}H_{22}(NO_3H)_9O_{11}$, $C_{24}H_{24}(NO_3H)_8O_{12}$.
1.488 1.483	Fiber still unresolved; soluble as above, but solutions more gelatinous and thready: $C_{24}H_{26}(NO_3H)_7O_{13}$.
1.476 1.472 1.469	Dissolve cotton to viscous solution; products precipitated by water; gelatinised by acetic ether; not by ether alcohol: $C_{24}H_{28}(NO_3H)_6O_{11}$.
1.463 1.460 1.455 1.450	Friable pulp; blued strongly by iodine in potassium iodide solution; insoluble in alcohol solvents: $C_{24}H_{30}(NO_3H)_5O_{15}$, $C_{24}H_{32}(NO_3H)_4O_{16}$.

8. Action of Hydrofluoric Acid.—The action of strong hydrofluoric acid on cotton and other vegetable fibers appears to be a peculiar one; a transparent, tough, flexible waterproof material being obtained. The product does not appear to resemble parchment obtained by the action of sulfuric acid. It is used as an insulating material and for making the carbon filaments of incandescent electric lamps.

Hydrofluoric acid and its compounds, sodium acid fluoride and the silico-fluoride, are used quite extensively in dilute solutions as cleansing agents for removing stains (especially of iron rust) from cotton fabrics in laundries and dry cleaning establishments.

9. Action of Organic Acids.—Organic acids in solution, even when moderately concentrated, do not appear to have any injurious action on cotton. The non-volatile acids, however, such as oxalic, tartaric, and citric acids, when allowed to dry into the fiber, act much in the same manner as mineral acids, especially at elevated temperatures.

Acetic acid, being volatile, exerts no destructive action; hence this latter acid is particularly suitable for use in the dyeing and printing of cotton goods, where the use of an acid is requisite.

The effect of certain acids on the strength of cotton is an important factor in printing. The following table shows the degree of weakening caused by various acids, strips of calico being printed with tragacanth pastes containing 20 grams of oxalic acid per liter, or an equivalent amount

of the other acids, and in the first case exposed for four hours to the ordinary temperature, and in the second case steamed for one hour:

Acid.	I. Percent.	II. Percent.
Oxalic	25	25
Tartaric	5	10
Ortho-phosphoric	1.5	15
Meta-phosphoric	31.5	35
Pyro-phosphoric	35.0	35.5
Phosphorous	27	28

Under similar conditions sulfocyanic acid has but a very slight tendering effect on printed cotton, even under the influence of steaming, but under the influence of hot dry air its tendering action is greater than that of oxalic acid. The addition of such substances as glucose appears to exert a protecting influence in connection with the above acids.

Rothwell [1] has investigated the relative effects of various organic acids on bleached cotton cloth. Pieces of thoroughly bleached cloth were padded in solutions of citric, tartaric and oxalic acids of various strengths, dried at a low temperature and then steamed for one hour at 5 lbs. pressure. The results are shown in the following tables: (the breaking strength of the original cloth was 139 lbs. and when steamed only, 136.5 lbs.)

Acid Used.	Solution, Percent.	Breaking Strength, Pounds.
Citric	1.25	79
Tartaric	1.25	52
Oxalic	1.25	Disintegrated
Citric	0.625	102
Tartaric	0.625	75
Oxalic	0.625	Disintegrated

It is evident, therefore, that tartaric acid has a much greater action on cotton than citric acid.

The destructive action of these acids on the cotton fiber is, perhaps, not so much of a chemical nature as mechanical, it being caused by the acids crystallising within the fiber and thus breaking the cell-wall. A dry heat, for instance, in connection with these acids is much more injurious than a moist heat, a fact which is of much importance in the drying of cotton prints, where the above-mentioned acids may have been used. Scheurer [2]

[1] *Dyer & Cal. Printer*, 1893. [2] *Bull. Soc. Ind. Mulh.*, August, 1900.

has studied the action of lactic, oxalic, tartaric, and citric acids on cotton, both in hot air and in steam. The result of his investigations showed: (1) Lactic acid tenders the fabric at least as much as tartaric and citric acids; oxalic acid being the most energetic in this respect; (2) the tendering takes place just as much before steaming as after.

Oxalic acid appears to have a peculiar effect on cotton; it has been noticed that if a piece of cotton cloth be printed with a thickened solution of oxalic acid, dried, and hung in a cool place for about twelve hours, and then well washed, the printed parts exhibit a direct affinity toward the basic dyes. The cotton so treated does not become greatly tendered or otherwise changed. Toward substantive dyes it exhibits considerably less attraction than ordinary cotton, while with alizarine dyes it is partially reactive. Tartaric and citric acids do not produce the same effect, nor does the neutral or acid oxalate of potassium.[1]

Scheurer [2] has also made some studies on the action of tartaric acid on cotton in connection with steaming as an operation in printing. He found that a sample treated with tartaric acid and exposed to a temperature of 110° C. for fifteen minutes showed as much tendering as a similar sample steamed at 98° to 99° C. for $1\frac{3}{4}$ hours. He concludes that when cotton is impregnated with tartaric acid it is very sensitive to the hygrometric condition of the steam.

Pilkington [3] has studied the tendering action on cotton of various organic acids, using the copper value of the treated cotton as a measure of the effect. His results are given in the following table:

Method of Treatment.	Copper Value.
Blank, with 3 grams of untreated cotton	1.35
Cloth treated with 5 grams per 100 cc. of tartaric acid alone	4.80
Cloth treated with 5 grams of tartaric acid and 1 gram of glaubersalt per 100 cc	4.57
Cloth treated with 5 grams of tartaric acid and 0.2 gram of glaubersalt per 100 cc	4.27
Cloth treated with 5 grams of tartaric acid and 0.4 gram of glaubersalt per 100 cc	3.40
Cloth treated with 5 grams of tartaric acid and 0.8 gram of glaubersalt per 100 cc	3.14
Cloth treated with 5 grams of tartaric acid and 1.6 grams of glaubersalt per 100 cc	2.82

[1] Fumaric and maleic acids have been suggested for use with cotton. In the dyeing of cotton, fumaric acid is unsuitable because of its insolubility; but for discharging in calico printing maleic acid is a good substitute for tartaric acid when used for certain colors, and for oxalic acid when used for discharging indigo. There is a danger, however, of tendering the fabric and corroding the copper rollers if much acid is used in the printing pastes.

[2] *Bull. Soc. Ind. Mulh.*, 1893.

[3] *Jour. Soc. Dyers & Col.*, 1915, p. 149.

This indicates that the presence of the neutral salt decreases the effect of the acid on the cotton. The following table gives the effect of various acids:

Acids at 2 Grams per 100 cc.	Copper Values.			
	Alone.	With 2 Grams of Glaubersalt per 100 cc.	With 20 Grams of Glaubersalt per 100 cc.	
			Found.	Corrected.
Oxalic	7.47	7.47	2.26	2.47
Tartaric	3.38	3.09	1.98	2.17
Citric	3.06	2.26	1.48	1.66

Fort and Pickles [1] give the following table showing the effect of various organic acids on the strength and elasticity of cotton yarns under conditions of padding and heating:

Padded with 2N Solution of	Dried at 20°–30° C.		Heated to 100° C.	
	Tensile Strength, Ounces.	Elongation, Percent.	Tensile Strength, Ounces.	Elongation, Percent.
Gray yarn	11.49	5.425		
Oxalic acid	7.08	3.75	1.87	1.48
Orthophosphoric acid	6.18	3.40		
Chloracetic acid	10.07	5.48	4.51	2.75
Tartaric acid	9.18	4.45	4.58	2.92
Formic acid	11.09	5.35	6.87	3.65
Acetic acid	11.53	6.10	7.7	4.45

Cross and Briggs [2] have shown that acetylation of cotton has the effect of making it resist the dyeing of direct cotton colors. The method consists in digesting the previously dried cotton with a mixture containing acetic anhydride, glacial acetic acid, and zinc chloride. The composition of the mixture varies with the degree of acetylation required. Suitable mixtures for hard yarn may be made as follows:

[1] *Jour. Soc. Dyers & Col.*, 1915, p. 256.
[2] *Jour. Soc. Dyers & Col.*, 1908, p. 189.

	Mixture A, For Gain of 26 Percent in Weight.	Mixture B, For Gain of 34 Percent in Weight.
Acetic anhydride	42	42
Acetyl chloride	11.5	11.5
Glacial acetic acid	50	25
Zinc oxide	6.5	6.5

Of " A " use twice the weight of the dry cotton and of " B " use 2.3 times the weight of the dry cotton. The cotton is impregnated with the mixture and the reaction is complete at the end of forty-eight hours at a temperature of 35° C., and the yarn is then washed off and dried. The yarn treated in this manner shows a gain in weight and resists very well dyeing with substantive colors, though showing an increased affinity for basic dyes. It also resists the action of cold caustic soda solution of mercerising strength. If a piece of the acetylated fabric be immersed for two or three minutes in caustic soda of 40° Tw., the stripes of ordinary cotton are mercerised and shrink, whilst the stripes of acetylated cotton resist the action. The fabric should be washed and soured as soon as the mercerisation is effected, otherwise a slow saponification of the acetate will take place. The mercerisation throws up the stripes, and the dyeing phenomena are in the main unchanged. Lastly, it may be mentioned that the acetylating process can be applied to cotton fabrics in the piece, and that the treatment imparts a finish and firmness resistant to careful washing (cold soaping). Other industrial advantages may possibly be derived from the fact that the normal hygroscopic moisture of these acetylated cottons is only about one-half of that of the original cotton.

10. Action of Tannins.—Tannic acid, unlike other acids, exhibits quite an affinity for cotton, the latter being capable of absorbing as much as 7 to 10 percent of its weight of tannic acid from an aqueous solution. Advantage is taken of this fact in the mordanting of cotton with tannic acid and tannins for the dyeing and printing of basic colors. Cotton exhibits a similar attraction for tungstic acid; the expense of this latter compound, however, precludes its adoption as a mordanting agent.

According to Georgevics [1] the absorption of tannin by cotton proceeds in accordance with the following equation:

$$\frac{\sqrt{C_t}}{C_f} = K(0.10 \text{ to } 0.12).$$

where C_t indicates the amount of tannin remaining in the bath calculated to 100 cc. of solution, and C_f indicates the quantity of tannin taken up by the fiber, calculated to 100 grams of cotton.

[1] *Färb. Zeit.*, 1899, p. 214.

According to Knecht [1] tannic acid is absorbed by cotton in its various forms as follows:

Form.	Tannic Acid Taken.	Tannic Acid Absorbed.
Bleached cotton	0.25 gram	0.0513 gram
Unbleached cotton	0.25 "	0.0563 "
Mercerised cotton	0.25 "	0.1033 "
Precipitated cellulose	0.25 "	0.1525 "

Though tannic acid is readily taken up by cotton, gallic acid is not absorbed under ordinary conditions. Gardner and Carter [2] give the relative amounts of tannins (and similar bodies) absorbed by cotton; 10 grams of cotton were soaked for three hours in a solution containing 1 gram of reagent per liter:

Reagent.	Percent. Absorbed.
Gallotannic acid	32
Catechutannic acid	32
Gallic acid	0
Pyrogallol	4.5
Phloroglucinol	24
Protocatechuic acid	0
Resorcinol	45
Salicylic acid	0
Guaiacol	0
Mendelic acid	7
Pyrocatechol	0

Koechlin found that cotton saturated with tannic acid in a solution containing 50 grams per liter was still able to absorb tannic acid from a solution containing 20 grams per liter. It retained the whole of its tannic acid in a solution containing 5 grams per liter, and only began to lose it when the strength was reduced to 2 grams.

The effect of adding other acids to the tannic acid solution is as follows (the acids being present in quantities equivalent to 4.5 grams of acetic acid per liter):

Solution.	Percent Absorbed.
Tannic acid alone (as above)	32
" +formic acid	48
" +acetic acid	48
" +propionic acid	48
" +citric acid	19
" +tartaric acid	20
" +sulfuric acid	18
" +hydrochloric acid	30
" +sodium acetate	16

[1] *Jour. Soc. Dyers & Col.*, 1892, p. 40. [2] *Jour. Soc. Dyers & Col.*, 1898, p. 143.

11. Action of Dilute Alkalies.—Though acids, in general, have such an injurious action on cotton, **alkalies,** on the other hand, are harmless under ordinary conditions. Dilute solutions of either the carbonated or caustic alkalies, even at a boiling temperature, if air is excluded, have no injurious effect on cotton.

In the **presence of air** alkaline solutions cause a hydrolysis of the cellulose in a manner similar to acids, with the result that the fiber is seriously weakened. The prolonged action of alkalies in the presence of air is an important one to bear in mind in the operations of bleaching, dyeing, or mercerising.

Boiling solutions of dilute alkalies dissolve or emulsify the waxy and fatty impurities encrusting the cotton fiber, hence these reagents are largely employed in the scouring of cotton goods.

The absence of air in the kier boiling of cotton goods previous to bleaching is a very important factor. The presence of air in the kier with the caustic alkali not only causes oxidation and consequent tendering and discoloration, but it also tends to produce air bubbles by expansion on heating, and these protect the fiber from the action of the alkali.

Scheurer [1] has shown that cotton fabrics when boiled out in 1 to 8 percent solutions of caustic soda at 150° C. if no trace of air is present indicate no weakening of the fiber; but if even minute quantities of air are present the fabric will be considerably weakened.

Weber [2] has observed that in dyeing cotton in alkaline baths the fiber may be considerably affected. Cotton was exposed during six hours to the action of oxygen and air, under such conditions as would actually obtain in dyeing, the cotton being immersed at the boiling point in baths containing 5 percent of various alkalies. The loss in weight of the cotton was observed with the following results:

Alkalies, 5 Percent.	Percent Loss in Weight with			
	Oxygen.	Steam and Oxygen.	Air.	Steam and Air.
Caustic soda	11.0	17.3	5.2	9.2
Caustic potash	22.8	29.8	8.4	11.7
Sodium carbonate	8.2	10.1	3.9	5.4
Potassium carbonate	13.7	16.4	5.3	6.9
Borax	5.9	6.8	2.2	2.8
Sodium phosphate	3.1	3.5	2.0	2.3

[1] *Bull. Ind. Soc. Mulh.*, 1888, p. 362.
[2] *Jour. Soc. Chem. Ind.*, 1893, p. 118.

In every case the fiber was found to have lost in tensile strength, and in some instances to be practically destroyed. The difference in the action of sodium and potassium compounds is somewhat remarkable, and would naturally lead us to avoid the use of caustic potash or potassium carbonate in the dyeing of cotton.

The loss of weight by boiling cotton in caustic soda solution is given as follows:

Strength of Solution, Percent.	Loss on Boiling for	
	30 Minutes, Percent.	1 Hour, Percent.
1	4.41	5.71
2.5	5.08	7.33

According to Bumeke and Wolffenstein,[1] when cotton is boiled eight times consecutively with 30 percent caustic soda solutions, the cellulose is completely dissolved to a dark brown solution. On acidifying this solution a copious precipitate of *acid cellulose* is obtained which seems to be identical with the *hydralcellulose* obtained by the action of hydrogen peroxide on cellulose.

The action of **alkaline solutions at high temperatures** (above 100° C.) on cotton appears, however, to be a destructive one. Tauss has shown that if cotton be digested with solutions of caustic soda under pressure, the fiber is attacked and converted into soluble products; the degree of decomposition depending on the pressure and the strength of the alkaline liquor, in accordance with the following table:

Pressure.	Strength of Alkali.	
	3 Percent Na_2O.	8 Percent Na_2O.
	Percent of Cotton Dissolved.	
1 atmosphere.....	12.1	22.0
5 atmospheres.....	15.4	58.0
10 "	20.3	59.0

Under these conditions it is probable that a hydration of the cellulose at first takes place, followed subsequently by a hydrolysis.

[1] *Berichte*, 1899, p. 2501.

Solutions of **ammonia** do not act on cotton until quite high temperatures are reached. According to the experiments of L. Vignon, at 200° C. ammonia reacts with cotton cellulose, the result being the evident formation of an amino-cellulose compound, the product evincing a greatly increased degree of absorption for dyestuff solutions, especially for the acid coloring matters, somewhat after the manner of animal fibers. The same effect is said to be obtained when cotton is treated with calcium chloride and ammonia at a temperature above 60° C.

The action of **alkaline solutions** on cotton under **high pressure** has an important bearing on the bleaching of this fiber, where it is subjected to such action by boiling with alkalies in pressure kiers. This phase of the question does not appear to have received much attention from either the practical bleacher or the theoretical chemist, but it would seem to be worthy of some degree of intelligent research on the part of both. The presence of small quantities of neutral salts (such as sodium chloride, sodium sulfate, alumina, calcium sulfate, iron, etc.) exert a distinctly inhibitory effect on the action of caustic soda in kier boiling of cotton.[1]

Trotman and Pentecost [2] give the following analyses of cotton properly and improperly boiled-out in kiers:

	Properly Boiled, Percent.	Improperly Boiled, Percent.
Mineral matter	0.05–0.75	1.00
Free fat	0.10–0.15	0.35–0.70
Fat as soap	Trace	0.25–0.50
Nitrogen	0.05–0.10	0.25–0.35

The relative scouring powers of different alkalies in kier boiling is also given, the loss in weight of the cotton being taken as a measure:

	Percent Loss.
Caustic potash	5.00
" soda	4.40
Sodium carbonate	3.70
" borate	2.80
" silicate	2.40

According to Francke [3] attempts have been made to carry out kier boiling and bleaching simultaneously, using sodium peroxide. A sample of Louisiana cotton with a fairly thick cuticle was used in yarn form. In spite of prolonged action with the peroxide in moderately strong alkali

[1] See Trotman, *Jour. Soc. Chem. Ind.*, 1910, p. 249.
[2] *Jour. Soc. Chem. Ind.*, 1910, p. 4.
[3] *Text. Berichte*, 1922, p. 108.

at 90°–100° C., the cuticle was not completely removed, but remained as yellowish spots on the yarn. With fibers having a thin cuticle a good product can be obtained, but even then there is too much non-cellulose left and fat removal is incomplete. Experiments were then carried out under pressure, the cuticle was removed and almost all accompanying substances, but the quantity of peroxide used was too great, owing to more impurities being removed, which then suffer oxidation at the expense of the peroxide. No formation of oxycellulose was observed in either case. If the bath is too alkaline oxycellulose is formed and vigorous oxygen evolution conditioned by catalysts sets in. With a bath much less alkaline than kier liquor, oxygen evolution is slow and regular, but even under pressure non-cellulose removal is not quite complete and yellowing is to be feared.

In the United States, processes for the simultaneous boiling-out and bleaching of cotton have been commercially introduced, using a strongly alkaline bath of sodium peroxide. The method has chiefly been employed in connection with the bleaching of cotton knit goods in the piece. Sodium perborate has also been used as the oxidising agent for simultaneous boiling-out and bleaching of cotton. This oxidising agent is less sensitive to decomposition at high temperatures than sodium peroxide, but it is higher in price and not so commercially available.

12. Action of Concentrated Solutions of Caustic Alkalies.—These have a peculiar effect on cotton; the fiber swells up, becomes cylindrical and semi-transparent, while the interior canal is almost entirely obliterated by the swelling of the cell-wall's. There is a marked gain in weight and strength, while the affinity of the cotton for coloring matters is materially increased. This effect was first noticed by John Mercer in 1844, and the reaction forms the basis of the modern process of **mercerising,** under which title a more complete and extensive discussion of this reaction will be found.

When cotton is heated with very concentrated caustic soda and finally melted with an excess of the alkali at a temperature above 200° C., the cellulose is decomposed with the formation principally of oxalic acid, acetic acid, formic acid, and hydrogen.

According to Schwalbe [1] in the various reactions between cotton and alkalies caustic potash appears to be somewhat less energetic than caustic soda.

Alkaline solutions prepared from the hydrates of calcium, barium and strontium have an action on cotton similar to that of caustic soda or caustic potash. Milk of lime is largely used for the boiling-out of cotton goods as a preparation for bleaching, though its use in this connection is more and more giving way to caustic soda. At high temperatures and under

[1] *Die Chemie die Zellulose,* p. 52.

pressure, as in kier boiling, the hydrates of the alkaline earth metals, if in the presence of air, also have a deteriorating influence on the strength of the cotton.

Solutions of **sodium sulfide** appear to have no immediate tendering action on cotton, even at a boiling temperature. If the sodium sulfide is dried into the fiber after about six weeks, the cotton shows a loss in strength of from 10 to 20 percent. Also, when sodium sulfide is dried into the fiber at 100° C., the tendering amounts to from 10 to 20 percent. Cotton containing copper sulfide or iron sulfide shows no appreciable amount of tendering.

When cotton is impregnated with **sulfur** and exposed to a damp atmosphere for several weeks, its tensile strength is reduced by about one-half. This is perhaps due to the oxidation of the sulfur into sulfurous and sulfuric acids.

If cotton, or other forms of cellulose, be treated with a concentrated solution of caustic soda to which a small amount of carbon disulfide has been added, the fibers swell up, become disintegrated, and finally form a gelatinous mass. This latter is soluble in a large amount of water, producing a very viscous solution, technically known as **viscose.**[1] From this solution hydrocellulose may be precipitated by sulfurous acid gas, as well as by various other reagents. Precipitation also occurs by simply allowing the solution to stand for some time, in which case the hydrated cellulose separates out as a jelly-like mass. Viscose has received several commercial applications, among which may be mentioned more especially the use of its solutions for the preparation of filaments of artificial silk, sausage casings, artificial horse-hair, staple fiber and cellulose films.

Though cotton does not show nearly the same degree of affinity for acids and alkalies as do the animal fibers, nevertheless it has been shown that cotton does absorb both acids and alkalies from their solutions, even when cold and dilute. The ratio of absorption appears to be 3 molecular parts of acid to 10 molecular parts of caustic alkali. Vignon, by a study of the thermochemical reactions of cotton, has shown that when this fiber is treated with acids or alkalies a liberation of heat takes place from which fact it would appear that cotton exhibits in some degree the properties of a very weak acid and a still weaker base. Vignon gives the following results in calories per 100 grams of cotton:

	KOH.	NaOH.	HCl.	H_2SO_4.
Raw cotton.....	1.30	1.08	0.65	0.60
Bleached cotton.....	2.27	2.20	0.65	0.58

13. Action of Oxidising Agents; Oxycellulose.—Strong oxidising agents, such as chromic acid, permanganates, chlorine, etc., in concen-

[1] This product has been treated more fully under the study of cellulose, as it is prepared technically from wood-pulp rather than from cotton.

trated solutions, readily attack cotton, converting it into oxycellulose. This substance appears to possess an increased affinity for dyestuffs, but it is of a structureless and brittle nature, hence its formation greatly tenders the fiber.

Scheurer [1] has studied the action of ammonium persulfate on cotton when steamed and found that this compound printed in the proportion of 5 to 10 grams per liter of gum tragacanth thickening, tenders the fiber to the extent of 10 percent. If used in a strength of 20 grams per liter the tendering amounts to 40 percent.

According to Vignon, there is a considerable difference in the heat liberated by the action of caustic soda on cellulose and oxycellulose, as follows:

Cellulose	0.74 cals.
Oxycellulose	1.30 cals.

It is said that oxycellulose is indifferent toward the tetrazo dyestuffs; and, in consequence, these may be employed for the purpose of detecting the presence of oxycellulose in cotton materials.

It may readily be understood, therefore, that in the processing of cotton materials in dyeing, bleaching, printing and finishing, there may often arise the possibility of the formation of oxycellulose, as in the processes of boiling-out in the kier, bleaching with hypochlorites, dyeing with Aniline Black, discharging with chlorates or chromates, the dyeing of Manganese Brown, and similar processes. In all such cases particular care must be taken in carrying out the process to avoid as far as possible the formation of oxycellulose. According to Nastukoff there are three modifications of oxycellulose, which he terms alpha-, beta-, and gamma-oxycellulose. These are distinguished from one another by their reaction with ammonia or dilute alkalies. None of the reactions of oxycellulose, however, such as the formation of a golden-yellow color on heating with dilute caustic soda, reduction of Fehling's solution, increased affinity for basic dyes, decreased affinity for some substantive dyes, formation of furfural by distillation with hydrochloric acid, the black coloration with Nessler's reagent, and similar reactions, are sufficiently definite to be made the basis of an accurate qualitative or quantitative determination of oxycellulose. It is doubtful if pure oxycellulose has ever been prepared, the product always being a mixture with unchanged cellulose, hydrated cellulose and hydrocellulose. The nearest approach, perhaps, to a quantitative determination of the alteration the cotton cellulose has undergone, is by obtaining the " copper number " of the material, which represents really the amount of reducing materials present that will react with Fehling's solution to precipitate cuprous oxide.

[1] *Bull. Soc. Ind. Mulh.*, 1900, August.

According to Vignon [1] oxycellulose may be prepared in the following manner: Cotton is first purified by successive treatment with a boiling solution of 1 percent sodium carbonate, boiling solution of 1 percent potassium hydrate, cold solution of 1 percent hydrochloric acid, and cold solution of sodium carbonate. The fiber is then well washed with water and alcohol, and dried. About 30 grams of this purified cotton is placed in a hot solution of 150 grams of potassium chlorate in 3000 cc. of water, and 125 cc. of hydrochloric acid is gradually added. The liquid is heated for one hour, then the cotton is removed, washed with water and alcohol and dried. The oxycellulose thus obtained is in the form of short brittle fibers which turn yellow when heated to 100° C. When boiled with solutions of Safranine and Methylene Blue a gram absorbs 0.007 and 0.006 gram, respectively, whereas ordinary cotton absorbs 0.001 and 0.002 gram per gram of fiber.

Oxycellulose appears to have the formula $C_{18}H_{26}O_{16}$. It dissolves in a mixture of nitric and sulfuric acids, and from the low number of hydroxyl groups reacting with the nitric acid, it may be concluded that the compound is both a condensed as well as an oxidised derivative of cellulose. Oxycellulose is soluble in dilute solutions of the alkalies, and on heating, the solutions develop a deep yellow color. When warmed with concentrated sulfuric acid it gives a pink color similar to that of mucic acid. In general it exhibits a close resemblance to the pectic group of colloidal carbohydrates.

It is probable that the oxidation products of cellulose obtained by different means do not all give the same oxycellulose, or, what is more probable, the oxycelluloses which have so far been studied are perhaps mixtures of various different bodies which have not yet been separated and isolated.

The oxidation of normal cellulose may be effected in either acid or alkaline liquors, and according to the oxidising agent employed and the method of operation, a number of different oxycelluloses may be produced. All of them, however, possess an affinity for basic dyes and yield furfural when distilled with hydrochloric acid. The quantity of furfural obtained serves as a measure of the amount of oxygen contained in the cellulose in excess of that required to satisfy the formula of normal cellulose ($C_6H_{10}O_5$).

Like hydrocellulose, oxycellulose has a strong affinity for water and is easily hydrated. Oxycellulose may be distinguished from hydrocellulose by its reaction with Nessler's reagent, with which it forms a dark gray precipitate. As indicated by its reactions it is probable that oxycellulose is characterised by the presence in the molecule of carbonyl (CO) and methoxy (OCH_3) groups.

[1] *Bull. Soc. Chim.*, 1898, p. 917.

While pure cellulose has but a slight reducing action on Fehling's solution, oxycellulose like hydrocellulose causes a considerable reduction; the reaction being so well defined that it may be employed as a test to determine the presence of oxycellulose in cotton that has been over-bleached. The determination of the *copper number*, or *copper value*, of bleached cotton indicates the relative degree of oxidation of the fiber and the amounts of hydrocellulose and oxycellulose formed; and as the weakening of the fiber is due to the formation of these two bodies, this test serves as a check on the proper control of the bleaching process. Hydrated cellulose does not reduce Fehling's solution, nor does its formation cause a tendering of the cotton.

Vignon [1] has studied the osazones of oxycellulose obtained by treating the oxidation products of cellulose with phenylhydrazine and acetic acid for thirty minutes at 80° C. The results are summed up in the following table:

Method of Preparation.	Yield per 100 Cellulose.	Nitrogen Fixed.	Phenyl-hydrazine Fixed.	Furfural.
Bleached cotton	.....	0.448	1.727	1.60
Oxycellulose by chlorate and hydrochloric acid	73.2	2.06	7.94	2.09
Oxycellulose by sodium hypochlorite	16.5	0.87	3.37	1.79
Oxycellulose by chromic and sulfuric acid:				
48 hours cold	85.0	1.82	7.03	3.00
120 hours cold	50.0	2.00	7.71	3.09
1 hour boiling	45.0	2.20	8.48	3.50

Moore [2] gives the effect of bleaching powder solutions of various strengths on cotton yarns, the results being shown in the following table:

Sample.	Strength of Bleach Solution, Grams Cl per Liter.	Tensile Strength, Ounces.
A	15.3	10.97
B	10.2	11.77
C	7.65	12.50
D	3.83	12.50
E	2.55	14.47
F	1.53	12.82
G	0.00	13.61

[1] *Comptes rendus*, 1899, p. 579. [2] *Jour. Soc. Dyers & Col.*, 1915, p. 183.

Knaggs[1] gives the following test for oxycellulose: Take a piece of cotton cloth which has been spotted with some oxycellulose-producing substance, such as bleaching powder, and after the oxycellulose has been formed, wash it with acid and then many times with water, dye it with a strong shade of Congo red, and then place the cloth in sufficient acid to get a blue color. The cotton is now carefully washed with a limited amount of water until the ordinary cotton has a good red shade, when the oxycellulose spot will appear as a black spot on the red ground. At this stage mercerised cotton, if present, appears red; hydrocellulose cannot be mistaken for the oxycellulose in this test.

Schwalbe and Robinoff[2] have shown that cellulose which has been chemically affected by bleaching undergoes hydrolysis when heated with water to high temperatures. It was found that in bleaching cotton with hypochlorite solutions followed by souring with hydrochloric acid, the formation of oxycellulose is promoted by the use of low strengths of acid. In addition to determinations of the solubility of the cellulose in dilute caustic soda the so-called "mucilage values" (the weight of the flocculent matter precipitated by alcohol after neutralisation of the alkaline extract) were also ascertained. Above 150° C. the mucilage value was much larger and consequently this temperature is stated as the "critical temperature" for cotton cellulose. A determination of the copper value of cotton treated with hot caustic soda solution shows that a concentration of 4 percent of alkali in the case of cold lyes was the most destructive. The products of hydrolysis formed by the action of 1 to 2 percent sodium hydroxide solutions appeared to undergo decomposition above 100° C. there being a decrease in the copper value. The decrease in the hydrolysis effected by lyes of 5 percent strength and over is probably due to the beginning of mercerisation or hydration. In this case American cotton gives a much higher copper value than Egyptian cotton.

A method of determining the amount of copper reduced in the Fehling's solution by oxycellulose has been devised by Schwalbe.[3] About 3 grams of air-dried cotton are boiled for fifteen minutes under a reflux condenser with 100 cc. of Fehling's solution and 200 cc. of water, the flask being constantly shaken. The hot liquid is then filtered, the residue washed with boiling water, and heated on the water-bath for fifteen minutes with 30 cc. of 6.5 percent nitric acid, and the dissolved copper is finally determined, preferably by the electrolytic method.[4] By this means the following copper values were obtained:

[1] *Jour. Soc. Dyers & Col.*, 1908, p. 112.

[2] *Zeit. angew. Chem.*, 1911, p. 256.

[3] *Berichte*, 1907, pp. 1347 and 4523.

[4] Hägglund (*Papier-Fabrik.*, 1909, p. 301) has suggested simplifying Schwalbe's method of determining the copper number. Instead of determining the copper elec-

Surgical cotton wool	1.6–1.8
Bleached mercerised yarn	1.6–1.9
Artificial silk (Glanzstoff)	1.1
Hydrocellulose	5.2–5.8
Parchment paper	4.2
Bleached sulfite wood pulp	3.9
Over-bleached wood pulp	19.3
Oxycellulose (bleaching powder on filter-paper)	7.9
Bleached cotton rag	6.5

There have been previously described by a number of investigators various chemical reactions which will more or less completely identify and describe oxycellulose. The detection of this alteration product of cellulose is especially valuable in the case of cotton bleaching and mercerising, and in many cases it indicates where faults are to be found in processes of textile finishing. It has been pointed out, however, that scarcely any of these previously described tests are capable of clearly distinguishing between oxycellulose and hydrocellulose, and this distinction is sometimes of considerable importance. The experimental evidence which is available indicates that the different forms of oxycellulose and hydrocellulose are probably to be considered as absorption compounds of peptised cellulose, and are the products resulting from the hydrolysis of the cellulose fiber. The dyeing properties of the cotton fiber depend mainly upon the colloidal condition of the cellulose portion, and the reducing properties of the fiber are due to the products of hydrolysis brought about by the action of various chemical operations. It is probable that the absorbed reducing substances are of the nature of an aldehyde in hydrocellulose and of the nature of an acid in oxycellulose. For the purpose of detecting the presence of either of these reducing substances (oxycellulose or hydrocellulose) in cotton fabrics it is recommended to prepare a reagent by adding a solution of silver nitrate to one of sodium thiosulfate with vigorous stirring, and then adding a solution of caustic soda so as to obtain a liquid containing 1 percent of silver nitrate, 4 percent of sodium thiosulfate, and 4 percent of sodium hydroxide. If the fabric to be examined is boiled in this solution or padded with it and then steamed, the portions containing oxycellulose will become stained. The effect will be enhanced if the material is first heated with a 1 percent solution of phenylhydrazine in glacial acetic acid and then washed with dilute acetic acid and subsequently treated as above with the silver solution.

14. Cellulose Peroxide.—Cotton and linen fabrics which have been bleached and acidified, without the subsequent use of an antichlor, some-

trolytically, the copper oxide is dissolved in a solution of ferrous sulfate in sulfuric acid, and then titrated with potassium permanganate See also Betrand, *Bull. Soc. Chem.*, 1906, p. 1285, and Freiberger, *Zeit. angew. Chem.*, 1917, p. 121.

times retain the property characteristic of "active oxygen" by liberating iodine from potassium iodide for a much longer time than is consistent with the survival of traces of residual hypochlorites. Cross and Bevan [1] call attention to a case where cotton cloth was bleached, soured, and washed under normal conditions, and yet retained an acid reaction and oxidising properties toward potassium iodide even after exhaustive washing with distilled water. The oxidising property was rapidly destroyed by boiling with water or by treatment with "antichlor." Cross and Bevan assume this character to be due to the formation of *cellulose peroxide*. Ditz [2] has observed that the same phenomenon can be produced by gradually heating cotton with an acid solution of ammonium persulfate up to a temperature of 80° C.

Bumcke and Wolffenstein [3] have shown that hydrogen peroxide reacting with cotton does not produce oxycellulose but brings about an hydrolysis with the formation of a product they call *hydralcellulose*. This is obtained by allowing strong hydrogen peroxide (60 percent) to act on cotton for ninety days, when the fiber will be completely converted into a white powder. It reduces Fehling's solution vigorously and is apparently of an aldehyde nature as it also reduces ammoniacal silver solution. By boiling with a 10 percent solution of caustic soda hydralcellulose is converted partly into cellulose and partly into *acid cellulose*, which though having no reducing properties, is soluble in caustic soda solution and in strong hydrochloric acid.

15. Action of Metallic Salts.—In its action toward various metallic salts cotton is very neutral, thereby differing considerably from both wool and silk. If the salts, however, are present in a very basic condition, cotton is capable of decomposing them and loosely fixing the metallic hydroxide. When cotton, for instance, is digested with a solution of barium hydrate, or with the basic salts of such metals as lead, zinc, copper, tin, aluminium, iron, chromium, cobalt, nickel, manganese, molybdenum, tungsten, etc., the fiber absorbs an appreciable quantity of the basic oxide though very much less than is the case with the animal fibers.

Michaelis [4] states that cotton has the property of precipitating, by mechanical surface attraction (*adsorption*), mordants such as salts of aluminium, iron, chromium, zinc, with weak acids, which on treatment in the dyeing vat form between the molecules of the fiber insoluble compounds with the dyestuffs.

Liechti and Suida [5] show the influence of the basicity of aluminium salts on their absorption by cotton. Solutions containing 200 grams per liter of the respective sulfates were used, as follows:

[1] *Zeit. angew. Chem.*, 1906, p. 2101.
[2] *Chem. Zeit.*, 1907, p. 833.
[3] *Berichte*, 1899, p. 2493.
[4] *Pflüger's Arch. ges. Physiol.*, vol. 97, pp. 634–640.
[5] *Jour. Soc. Chem. Ind.*, 1883, p. 537.

Composition of Sulfate.	Percent Al_2O_3 Absorbed.
$Al_2(SO_4)_3 \cdot 18H_2O$ (normal)	12.9
$Al(SO_4) \cdot (OH)_6$	51.0
$Al_4(SO_4)_3 \cdot (OH)_4$	58.7
$Al_2(SO_4) \cdot (OH)_4$	—

The last dissociated too rapidly for experimentation. The fact that a salt is a basic one is not any indication that it will act as a mordant; the basic chlorides and oxychlorides of aluminium are not mordants.

Haller [1] has investigated the action of **mordants** on cotton from the point of view of the adsorptive capacity of cellulose. Cotton cellulose is considered as being in the form of a gel, both as raw cotton and after purification with alkali. In the experiments the cotton was left for forty-eight hours in the solution of the salt concerned. The amount of metallic oxide was then determined in the filtrate and referred to the amount of cotton used. It was then possible to find the relation between the purity of the cotton and its adsorptive capacity. Indian cotton, for instance, which can be wet only with difficulty, adsorbs salts (aluminium sulfate, aluminium acetate, and lead acetate) the least; the reverse being true of both American and Egyptian cotton. Of the three salts, lead acetate was adsorbed to the greatest extent, with aluminium acetate a negative adsorption was noticed; that is, the cotton took up nothing from this solution, but on the other hand, gave up certain of its mineral constituents to the solution, the more highly purified the cotton the greater was this loss. This phenomenon, however, may be explained by assuming that the cotton fiber does adsorb some of the aluminium compound but also gives up more of its own mineral matter, in consequence of which the treated cotton shows less ash than at first, and therefore the negative adsorption is only apparent. In the case of lead acetate only raw cotton will adsorb and hold fast the lead salt even to subsequent washing; with purified cotton (boiled-out and bleached) the lead salt at first adsorbed may be completely washed out again. Schwalbe and Becker [2] have shown that both hydrocellulose and oxycellulose take up more alumina than cellulose itself. These discussions, though seemingly of only theoretical interest, have considerable bearing on the mordanting of cotton and the sizing of paper.

Salts of stannic acid (sodium stannate) are also absorbed by cotton to quite a marked degree. In this instance, stannic acid appears to act much in the same manner as tannic acid.

Many salts, especially those of an acid nature, will tender the cotton fiber, probably due to the liberation and drying-in of the acid. Consequently, such salts should be avoided or used very carefully with cotton, and any excess should be thoroughly eliminated by subsequent washing before the material dries. Magnesium chloride is largely used in the preparation of finishes for cotton goods, and tendering of the fiber may

[1] *Chem. Zeit.*, 1918, p. 597. [2] *Zeit. angew. Chem.*, 1919, pp. 265 and 355.

occur if fabrics containing this salt are subjected to high temperatures such as experienced in drying over hot rolls.

The following facts have been determined with reference to the use of magnesium chloride on cotton goods:

(1) An aqueous solution of magnesium chloride does not begin to decompose until a temperature of 223° F. is reached, neither alone nor in the presence of an excess of air, not in steam, nor in the presence of cellulose, nor in admixture with other ordinary finishing agents.

(2) The amount of hydrochloric acid generated up to a temperature of 480° F. is quite small, aggregating only about 2 per cent of the whole.

(3) The deterioration of cotton finished with magnesium chloride does not take place below 223° F. Such cotton may therefore be safely treated with steam at the atmospheric pressure.

(4) Cotton finished with magnesium chloride should not be subjected to high temperatures, especially such treatment should not be prolonged. The limiting temperature for the drying of such material should be 212° F.

(5) If a temperature of 212° F. in drying is not exceeded, magnesium chloride may be employed without danger in the finishing of cotton fabrics. It should not be used, however, if such material is to be subjected to steam under pressure or to ironing.

Zinc chloride is sometimes employed in sizing compounds used on cotton warps and it has been found when such material is singed or subjected to high temperatures the fiber becomes tendered. Flintoff [2] has investigated this matter and has come to the conclusion that the tendering action is not so much due to the formation of free hydrochloric acid as it is to the formation of a hydrated cellulose zinc oxide compound. He showed by experiment that if cotton were treated with zinc chloride solution and steamed, the fibers became swollen and translucent, and in many respects resembled mercerised cotton.

In studying the effects of metallic salts on cotton it is important to distinguish between the action of acid, neutral, basic and alkaline salts. Acid salts are those which readily become dissociated with the liberation of free acid, especially when in solution or when heated. Such mineral salts react in a manner very similar to free mineral acids, only not to the same degree. They tend to destroy the cellulose of the cotton with the formation of hydrocellulose, and a consequent weakening of the fiber. Alum, aluminium chloride, magnesium chloride, sodium bisulfate and stannic chloride are examples of acid salts. Neutral salts appear to exert little or no action on cellulose or cotton under ordinary conditions; such salts are common salt, glaubersalt, magnesium sulfate and the like. Basic salts are those in which the metallic base dominates in strength the acid radical to which it is attached, so that in solution the salt tends to liberate its base. Many metallic salts are of this character, especially when the combined acid is an organic one, such as acetic, lactic, tartaric, and the like. The acetate of iron or aluminium, for example, is rather easily dissociated with the liberation of the free metallic hydrate or oxide.

[2] *Jour. Soc. Dyers & Col.*, 1899, p. 154.

The reaction of such salts with cotton is to undergo a slight degree of dissociation so that the fiber takes up a small amount of the metallic hydrate. The action of cotton in this respect however, is not nearly as strong as with wool or silk, and on this account it is not possible to mordant cotton in the same manner or as readily as the other two fibers mentioned. Alkaline salts include such bodies as sodium carbonate (soda ash) and sodium sulfide. In these cases the combined acid radical is so weak as compared with the basic nature of the metal, that the salt exhibits the properties of a strong alkali, and the reactions of these with cotton have already been considered.

Barium chlorate may be employed for treating cotton which is subsequently to be destroyed for pattern effects. Lace and embroidery effects are obtained by making these effects on a base of cotton cloth which has been treated with a solution of barium chlorate and then dried at a low temperature. This salt does not injure the needles used in the embroidery, and when the fabric is heated for a short time at 320° F. it becomes disintegrated and may be brushed away from the lace or embroidery.

Opaline and plastic effects on fabrics are given by precipitates from sodium tungstate and barium chloride solutions in the hydrosulfite bath. The method is particularly successful for mercerised cotton.

The action of various salts heated in contact with cotton is given by Ford and Pickles.[1] The results are shown in the following table:

Salts Used in Normal Solution.	After Padding, Drying Below 50° C. and Treating to 100° C.	
	Tensile Strength, Ounces.	Elongation, Percent.
Sodium chloride	11.69	5.63
Sodium sulfate	10.94	5.62
Magnesium chloride	9.11	5.05
Zinc chloride	8.19	4.88
Zinc chloride with sodium chloride	9.81	4.83
Magnesium chloride with sodium chloride	10.38	5.68
Magnesium chloride with zinc chloride	9.12	5.28
Magnesium chloride with sodium sulfate	11.66	6.00
Magnesium sulfate with sodium chloride	10.84	5.75
Magnesium sulfate	11.40	5.65
Water alone	10.73	5.9

Scheurer[2] from experiments with iron mordants on cotton finds that after aging for twelve hours at 36 to 40° C. a tendering of 15 percent is noticed, and after dunging the average tendering is 25 percent.

The rapid disintegration of textile fabrics when exposed to sea water

[1] *Jour. Soc. Dyers & Col.*, 1915, p. 257. [2] *Bull. Soc. Ind. Mulh.*, 1893.

is well known. Under the condition of complete immersion most textile fibers become completely rotted in three to five weeks. Experiments have pointed to the conclusion that, in the case of cotton, the change brought about is in some way conditioned by the reactivity of the hydroxyl groups in the cellulose molecule. This result has led to investigation of acetate silk made from cellulose triacetate. After four months' immersion in sea water no appreciable change had taken place, which fact has caused the acetate silk to be recommended for marine biological use. Stated briefly, the results of the investigations are as follows:

(1) Fabrics of cotton and silk are destroyed by immersion in sea water for three weeks, wool lasting somewhat longer.

(2) The destructive action has been shown in the case of cellulose to be due to micro-organisms and not to oxygen, light, or the salts present.

(3) In its nature it resembles the "mechanical" breakdown of cotton sometimes observed under the "beetling" process.

(4) If cotton is acetylated to the mono-acetate stage so that its structural qualities are preserved, the resulting material is very resistant to sea water.

(5) Cellulose acetate silk has proved capable of withstanding the action of sea water for months.

Hübner and Malwin [1] have studied the effect of various metallic salt solutions and finishing compounds on the "ripping" strain of cotton fabrics. Tests were made both with 1 percent solutions and with saturated solutions. The following table gives the results of the tests in terms of the mean figures for the warp and filling:

1 Percent Solutions.	Ripping Strain.			Tensile Strain.		
	Air-dry.	100° C.	120° C.	Air-dry.	100° C.	120° C.
Original fabric	100.0	95.4	98.3	100	101.9	102.2
Calcium chloride	103.3	97.9	97.6	96.5	96.7	87.8
Magnesium chloride	102.0	99.9	100.1	95.8	93.5	96.6
Zinc chloride	98.1	93.3	95.1	103.7	100.8	91.6
Sodium sulfate	107.0	111.8	106.4	96.8	96.9	98.5
Sodium sulfate	101.8	99.9	106.5	94.7	94.1	94.4
Sodium sulfide	105.6	104.7	106.8	103.0	95.6	93.9
Boric acid	100.7	96.2	85.5	96.3	91.9	88.1
Borax	104.8	107.2	94.2	94.1	90.7	93.7
Sodium chloride	113.4	115.0	101.3	99.4	98.3	97 5
Sodium carbonate	112.1	108.0	100.1	99.0	97.6	98.8
Sodium phosphate	110.6	110.8	112.1	95.2	104.6	103.0
Sodium acetate	109.3	114.0	100.9	103.8	94.9	97.8
Sodium stannate	74.0	76.4	78.6	105.0	94.1	99.3
Starch solution	112.4	117.5	102.6	96.9	89.3	86.1
Soap solution	136.9	146.2	128.1	94.6	91.4	90.9

[1] *Jour. Soc. Chem. Ind.*, 1923, p. 66.

It would seem, therefore, that the effect of 1 percent solutions of these salts on the tensile strain is negligible; the same is also true of the ripping strain with the single exception of sodium stannate, and this is such an anomalous exception that we are inclined to believe that there must be some error in the results given.

Saturated Solutions.	Ripping Strain.		Tensile Strain.	
	Air-dry.	100° C.	Air-dry.	100° C.
Calcium chloride	64.0	47.2	73.6	63.8
Magnesium chloride	66.1	62.1	89.9	74.6
Zinc chloride (110° Tw.)	70.1	31.0	84.4	56.1
Sodium sulfate	63.8	60.3	96.8	91.7
Sodium sulfite	74.1	67.6	92.9	90.4
Sodium sulfide	56.7	39.6	70.7	72.5
Boric acid	89.7	80.6	88.8	75.1
Borax	85.5	75.2	86.3	85.0
Sodium chloride	76.8	74.0	98.0	93.3
Sodium carbonate	65.2	61.4	90.1	88.3
Sodium phosphate	99.7	100.8	94.7	89.4
Sodium acetate	69.8	53.8	103.1	99.2
Sodium stannate	64.6	51.5	98.2	93.1

From this it will be seen that the effect of saturated solutions of salts in many cases is very marked, the greatest reduction in the ripping strain being produced by zinc chloride, with sodium sulfide next in order. Sodium phosphate solution has practically no effect on the ripping strain.

16. Weighting of Cotton Yarns.—Cotton yarn may be weighted to a considerable extent, when dyed with the direct colors, by adding magnesium sulfate (Epsom salt) to the dye bath, together with a small quantity of dextrin. Owing to danger of imperfections in the color, such as unevenness and cloudiness, it is perhaps better to use a separate bath after the dyeing for the purpose of weighting. This will be especially true if it is desired to weight to any considerable extent. The following process is a typical example of weighting cotton yarn which has been dyed with direct colors. For 100 lbs. of cotton yarn use a bath containing about 160 gallons of water; add 100 lbs. of magnesium sulfate, 15 lbs. of dextrin, and 2 lbs. of glycerol. Have the temperature of the bath at about 120° F. The cotton yarn is entered into this bath and turned for twenty minutes, or until the fiber is thoroughly saturated with the solution. It is then removed, hydroextracted and dried. Such a treatment as this will give a weighting of about 10 to 12 percent to the cotton yarn. The bath is by no means exhausted, and may be freshened up by the addition of a small amount of magnesium sulfate and dextrin till

it is brought back to the same hydrometer test as at first, and succeeding lots of cotton may be treated as above. The glycerol is added for the purpose of preventing the weighting material from giving the fiber a stiff handle. Instead of employing glycerol a small amount of Turkey-red oil or soluble softener may be used. Soaps, however, cannot be employed in this connection, as they would be precipitated by the magnesium salt present, forming an insoluble metallic soap. By this process of weighting, yarn which is dyed in even, bright and delicate colors may be successfully treated, as the weighting material does not add any color of itself to the yarn. Of other metallic salts, zinc sulfate has also been suggested as weighting material, as its presence furthermore is highly antiseptic and prevents the growth of mildew or the origin of fermentation in the cotton which contains it. Zinc sulfate, however, is more expensive than magnesium sulfate and is more or less poisonous in character, hence would be objected to in the majority of instances. Barium chloride might also be employed for weighting, but it is more expensive than magnesium sulfate, and furthermore barium salts are also poisonous. Calcium chloride is another metallic salt the use of which has been suggested for weighting cotton yarns, but this substance is so highly hygroscopic that it is difficult to understand how it could be used with advantage on cotton yarns, as it would absorb moisture to such an extent that when present in any considerable quantity on the yarn it would cause the latter to become damp and sticky.

This method of weighting yarns does not furnish a weighting material which is insoluble in water, hence the weighting would be easily removed if the yarn or the material into which it is to be manufactured were washed with water or scoured with soap. Furthermore, yarn weighted in this manner with magnesium sulfate, if scoured subsequently in the cloth with soap solutions, would furnish a very defective material, as the magnesium soap, which would be formed by the action of the soap with the magnesium sulfate, is insoluble in water and is of sticky nature, so that it is very difficult to remove completely from the fiber. This will naturally lead to bad defects if a subsequent scouring operation is necessary.

In case the cotton to be weighted is dyed in black or in dull, heavy shades, such as blues or violets, a considerable degree of weighting may be obtained by treating the dyed yarn alternately with baths of sumac extract and pyrolignite of iron. This will cause the formation on the fiber of an insoluble tannate of iron, and the weighting thus obtained is of a permanent character. This tannate of iron, however, is of a black color, and so has the effect of darkening and dulling the color which may be dyed on the yarn in the first place. The tannic acid of the sumac and the iron salt have the effect of making the fiber very harsh if any considerable amount of these materials is fixed on the cotton, conse-

quently the amount of weighting in this case is rather limited. It is possible, however, by this means to obtain a weighting of about 5 percent without very materially injuring the quality of the yarn, if a small amount of glycerol or oil is employed for the purpose of softening the fiber and thus in some degree neutralising the harshening effect of the weighting materials.

17. Action of Coloring Matters.—In its behavior toward coloring matters cotton differs most markedly from the animal fibers. Of the natural dyestuffs, only a few color the cotton fiber without a mordant; with the coal-tar colors, cotton exhibits no affinity for most of the acid or basic dyes, and these can only be applied on a suitable mordant. The substantive colors, however, are readily dyed on cotton, in a direct manner, and since their introduction the methods of cotton dyeing have been practically revolutionised.

There has been much discussion as to whether the phenomena of dyeing with reference to cotton are of a physical or chemical nature. From the view-point of colloidal chemistry it would seem that the process of dyeing is one of *adsorption*, and the principal force operating is capillary action.[1] Unlike the animal fibers, cotton does not possess groups of a very distinctly active chemical nature; that is to say, it cannot be said to noticeably exhibit either acid or basic properties. The only groups in cotton cellulose which may be considered chemically active are the hydroxyl groups. These can be rendered inactive by acetylation, and it has been shown [2] that cotton so treated does not exhibit any difference in dyeing properties from ordinary cotton, and this leads us to the assumption that in the case of cotton, the phenomena of dyeing rest on a physical dissociation of the dyestuff molecule determined by the fiber; that is to say, the process of dyeing with reference to cotton must be attributed (in great measure at least) to the action of dissociation, dissolution, and capillarity; in other words, to purely physical or physico-chemical causes; and purely chemical reactions, if they come into play at all, are of secondary importance.

The method of combination between fiber and dyestuff is explained by Krafft [3] as a separation of colloid salts on or in the fiber. With basic colors, the soaps and the colloid tannin are chiefly used for the purpose of forming insoluble colloid compounds with the dyes; with acid colors metallic mordants which are themselves colloids, like the hydrates of iron, aluminium, cromium and tin, are used. These conditions are necessary to produce fast colors with dyes of molecular weight and of small dyeing capacity on the cotton fiber. With azo dyes of high molecular weight, which dye cotton directly, it is probable that they are all colloidal substances. Tannin, which is the most important fixing agent in the dyeing of cotton, has a high molecular weight and is a colloid. Both ferric hydrate and aluminium hydrate are colloidal.

[1] See Rosenthal, *Bull. Soc. Chem.*, 1911, pp. 12 and 224.

[2] Suida, *Färber-Zeit.*, 1905.

[3] *Berichte*, 1899, p. 1608.

Kuhn [1] finds there is a greater deposition of coloring matter along the lumen of the fiber according as the dyeing process is more complete, although even in the best dyed fibers the largest proportion of dyestuff is deposited on the outer surface. De Mosenthal has pointed out that a single fiber does not absorb coloring matter by capillary attraction, but the dyestuff solution apparently rises between the fibers and passes into them through the pores in the cell-wall. Crum believed that the coloring matter was deposited within the central canal or lumen; but O'Neill showed that this was seldom the case, the whole cell-wall being colored in a uniform manner. According to Georgievics a porous structure of the cotton fiber could hardly be considered essential to its dyeing, for fibers not possessing any organic structure at all (such as the various forms of artificial silk) can be dyed in practically the same manner as cotton. Recent work by Haller has shown that cotton dyed with chrome yellow when examined in cross-section even under a magnification of 1000 diameters, failed to exhibit any trace of porous structure. The cell-walls were homogeneously impregnated with the color in a very fine state of division. Haller has shown also that cotton fibers still attached to the seed-shell dye as satisfactorily as ordinary cotton fibers. In this case both ends of the fiber are closed, and the central canal is not exposed to the capillarity of color solutions; hence it is to be concluded that the central canal in the cotton fiber does not play any important part in the dyeing process.

Minajeff [2] by comparing the action of dyestuffs on artificial silk and cotton concludes with reference to the latter that (*a*) the cuticle of the bleached fiber has no influence on the dyeing process, (*b*) the lamellar structure of cotton plays no part in differentiating its dyeing action from that of artificial silk, and (*c*) the canal in the cotton fiber plays no important rôle, mordants and color-lobes being deposited within the canal to only a very limited extent. The determining factors appear to be thickness, density, and capillarity, rather than microscopic structure.

Rona and Michaelis [3] affirm that the apparent absorptive power of cotton for dyes is really due to an exchange of mineral matter for dye, and support this view by the fact that in the absorption of Methylene Blue the chlorine content and the hydrogen ion concentration of the solution remain constant.

Cotton yarn may be prepared so as to "resist" dyeing with direct cotton colors, by treatment with mixed nitric and sulfuric acids so as to produce a hexanitrated cellulose. Fothergill [4] has shown that if cotton yarn be mordanted with tannate of tin it becomes practically resistant to the direct cotton colors, and if woven in connection with untreated yarn gives a "mélange" or two-color effect.

[1] *Die Baumwolle*, p. 183.
[2] *Zeit. Färb. Ind.*, 1909, p. 236.
[3] *Biochem. Zeitsch.*, 1920, pp. 19–29.
[4] *Jour. Soc. Dyers & Col.*, 1907, p. 251.

18. Effect of Chemical Processes on Cotton Fabrics.—The various operations of boiling-out, bleaching and dyeing, and mercerising exert considerable influence on the weight and strength of cotton fabrics. E. Midgley [1] has made some interesting tests on this subject, the results of which are given in the following tables:

Effect of Processes on Weight

Treatment.	Original Weight.	After Treatment.						
		2/40's American.	2/120's Sea-island.	1/50's Egyptian.	2/40's Egyptian.	2/60's Egyptian.	1/40's Egyptian.	Mean.
Boiling water....	100	96	95	95	97	97	97	96
Bleached.....	100	95	93	93	93	95	95	94
Mercerised.....	100	98	96	96	98	98	97	97
Aniline Black....	100	105	103	103	104	104	104	104
Logwood Black...	100	105	105	107	105	106	107	106

Average Results Illustrating the Influence of Various Treatments on Three Types of Cotton Yarns: 2/120's Sea-island (Combed); 2/40's American (Carded); 1/50's Egyptian (Combed)

	Weight.	Length.	Strength.	Elongation.
1. Gray.....	100	100	100	100
2. Bleached—				
(*a*) Chlorine.....	97	97	94	92
(*b*) Permanganate.....	97	96	93	96
(*c*) Peroxide.....	93	96	87	102
Average.....	$95\frac{2}{3}$	$96\frac{1}{3}$	$91\frac{1}{3}$	93
3. Dyed Black—				
(*a*) Aniline.....	110	96	122	98
(*b*) Sulfur.....	104	96	108	93
Average.....	107	96	115	95
4. Boiled in Water—				
(*a*) 2 hours.....	97	97	104	104
(*b*) 4 hours.....	94	97	100	102
(*c*) 6 hours.....	94	97	100	98
Average.....	95	97	$101\frac{1}{3}$	101

[1] *Textile Manufacturer.*

Pickles [1] has made a detailed investigation of the effect of various treatments on cotton yarn. The yarn employed for the tests was 2/40's and 2/60's Egyptian cotton, and the results are shown in the accompanying tables:

Process.	Weight After Treatment.	Length After Treatment.	Strength.	Elongation.	Moisture Regain, Percent.
Gray yarn, 2/40's	100.0	100	100.0	100.0	8.8
Boiling water without tension	97.5	100	101.7	102.9	8.1
Boiling water with tension	97.7	100	100.6	100.0	8.0
Bleaching powder	94.4	100	98.2	80.7	8.4
Permanganate bleach	93.9	100	91.3	89.8	8.7
Mercerised with tension	98.7	100	125.1	75.5	11.1
Mercerised without tension	100.4	83	136.9	196.0	13.1
Developed black	99.7	100	96.1	93.1	8.9
Sulfur black	104.1	100	103.5	90.0	8.8
Direct black	99.1	100	98.1	93.9	8.8
Logwood black	105.6	100	107.0	90.0	8.8

Similar tests were also made with single yarns of American, Sea-island and Egyptian cotton with about the same relative results.

19. Action of Ferments on Cotton.—Though resistant to the action of moths and insects in general, cotton is liable to undergo fermentation as is evidenced by the formation of mildew on cotton fabrics stored in damp places. Though this fermentation is often induced by the presence of more or less starchy matter contained in the sizing materials used in finishing the goods, yet pure cellulose itself can also be fermented, and Omeliansky has succeeded in isolating the particular bacillus which destroys cellulose.

According to Knecht [2] human saliva has a peculiar and distinct effect on cotton. His experiments show that a piece of bleached calico, saturated with saliva, will absorb considerably more dyestuff on dyeing with substantive colors than untreated cotton. This is not due to mucus, or to any of the salts contained in the saliva, but probably to the enzyme ptyalin, since the saliva loses the power of producing the effect after boiling. Of other enzymes, diastase was also found to have some action, though very slight. This action of saliva on cotton may explain some faults arising in dyeing cotton pieces.

Malt extracts have long been employed to assist in the removal of starch from sized fabrics, but attention has recently been directed to the

[1] *Report Bradford Techn. College.* 1910.

[2] *Jour. Soc. Dyers & Col.*, 1905, p. 189.

application of enzymes as a substitute for the alkali boil for the removal of the various impurities present in the raw fiber. It has shown nearly thirty years ago by Herbert [1] that bacteria which destroy cellulose do not attack the cellulose molecule proper until adherent pectins, gums, and tannins have been decomposed. Recently, Levine [2] has examined the action of *B. amylolyticus*, *B. fimi*, *B. bibulus*, *B. carotovorous*, and *B. subtilis* on unbleached cotton in a nutrient medium containing dipotassium hydrogen phosphate, magnesium sulfate, sodium chloride, ammonium sulfate and lime. He found that the nitrogenous substances and constituents which are soluble in ether are efficiently removed, but that the impurities soluble in alcohol are only attacked by *B. carotovorous* and *B. subtilis*. In the case of *B. bibulus* and *B. fimi*, the cloth became weaker, which may have been due to the action of air on parts incompletely submerged. On the large scale, the material was incubated with the bacterial culture for periods ranging from twenty-four to seventy-two hours, with encouraging results. Röhm [3] has patented the substitution of the alkali boil by a steep in a 0.1 percent solution of pancreatin at 68° to 104° F. for some hours, other enzymes such as papayotin ferments serving the same end.

20. Action of Mildew on Cotton.—Mildew does not appear as often on white and colored as on gray (unbleached) cloth, which, being sized, is much more liable to this defect. The essential conditions for the production of mildew appear to be (1) dampness, (2) lack of fresh air, (3) the presence of certain bodies (such as flour, etc.) suitable as foods for the fungi. The more common varieties of mildew are:

(1) Green mildew, a common form generally due to *Penicillium glaucum* and *Aspergillus glaucus*, which are closely allied, but which are distinguishable from the way in which the spores are attached. In the former the spores are on branches, while in the latter they are attached to the head; they grow rapidly and generally form rather large patches.

(2) Brown mildew is frequently found on cloth, and is due to various species of fungi, of which *Puccinia graminis* is perhaps the most common. This and the brick-red mildew noticed below are frequently mistaken for iron stains, the color of which they closely resemble. They are easily distinguished by the manner in which they occur in small spots, often of a ring shape, and they do not give the Prussian-blue test.

(3) Brick-red mildew is not very frequent and the fungus which causes it has not been definitely recognised; it grows rapidly at first, but has no great vitality and after a time the development stops.

(4) Yellow mildew, a common variety occurring in large irregular patches and spots. Not requiring much air for its development, it extends much more into the folds of the cloth than do most of the other kinds. It is a yellow variety of the *Aspergillus glaucus* (*Eurotium*) and may also be *Oidium aurantiacum*.

[1] *Ann. Agronom.*, 1892, p. 536.
[2] *Jour. Ind. Eng. Chem.*, 1916, p. 298.
[3] *Brit. Pat.* 100,224 of 1916.

(5) Black mildew, due often to fungi belonging to the genus *Tilletia*, is occasionally found; it is very rapid in growth.

(6) Purple mildew is rare.

(7) Bright pink mildew is also rare.

With the help of the viscose treatment it is possible to show that changes occur in the structure of the cotton fibers when attacked by bacteria. A method, based on this observation, is described for the quantitative determination of the bacterial deterioration of cotton. Applied to cottons of various origins, this "swelling test" shows that a difference exists in the susceptibility to attack by bacteria, and that Indian cottons deteriorate quicker than American samples. Samples of

FIG. 213.—Cotton Fibers Infected with Mildew.

cotton grown in India from American seed were found to be as resistant to attack as American cottons.

From investigations by Denham [1] on the destruction of cotton fibers by micro-organisms, it is apparent that serious damage may exist in the cotton before any indication of its presence can be detected by the usual tests, and that one or two points of infection may seriously interfere with the spinning qualities of the fiber. It therefore becomes of importance to guard against the possible development of micro-organisms in all stages of manufacture, particularly in those processes, such as conditioning, which involve the addition of moisture to cotton. Photomicrographs of infected cotton fibers are shown in Figs. 213 and 214.

Goods to be paraffined should be dyed by a method which incorporates in the goods mildew-resisting qualities before the waxing occurs, and

[1] *Jour. Text. Inst.*, 1922, p. 240.

this is most readily done by dyeing with cutch instead of with coal-tar dye products. Mineral dyed khaki has considerable antiseptic qualities due to the oxide producing the color, and mineral dyed khaki paraffined is a much better fabric than goods dyed with sulfur colors, or direct colors, and then waxed. White paraffined duck goods without an antiseptic preliminary treatment have little resistance to mildew, but are very cheap, and for some purposes very satisfactory fabrics.

Cotton fabrics, especially canvas, may also be made mildew-proof by treatment with cuprammonium solution. This reagent partially dissolves the cellulose and forms a film or varnish over the fiber. The product has been manufactured to some extent, under the name of Willesden canvas, for use as tarpaulin and tent material. The process, however, is

Fig. 214.—Fibers of Cotton Infected with Mildew.

rather costly. These cuprammonium fabrics are by far the most mildew-proof of all commercially produced finishes. Their color is not entirely permanent to light, the green color due to the copper fading out as the compound becomes reduced after severe exposure; but the copper is nevertheless there in a leuco or white state and the change in color does not seem to diminish the mildew-proof quality of the goods. The green color may be modified to some extent, either by chemical fumes which change the copper superficially to sulfide or oxide, by dyeing the fabric before the treatment, or by after-treatment with colored varnishes.

Some zinc solutions have a similar property but do not make as good coatings and lack some of the desirable features of the copper solutions. The latter can be modified either to leave the goods soft yet saturated, or to glaze the yarns and fibers, and the latter result is a most beautiful, shining, silky, pale green or dark green fabric.

21. Testing Canvas for Mildew Resistance.—The standard method is to collect a variety of mildew growths by exposing bread crust or similar material to the air for a few hours, and then confining it with a little water in a closed container, kept in a warm, dark place. Mould can readily be obtained from diastafor, and other substances common in the mill, by the same treatment. The tester should endeavor to secure a considerable variety of mildew. It will be found convenient to use the lower half of a desiccator to hold the growths, and suspend samples within from wires. A moist condition should be maintained inside, and the mildew jar kept in a cupboard away from the light. Test samples should not develop mildew growths in five days of this exposure.

The development and action of mildew on cotton fabrics has been thoroughly studied by Levine and Veitch,[1] and they have also devised methods to determine the mildew resistance of such fabrics, particularly for use in the army and navy. Mildewing is due to the development of various mould growths on and in the fabric. The number of species responsible for the deterioration is large, but chief among them are the species of *Alternaria*, of *Cladosporium*, and some *Mucors*. The simultaneous occurrence of different kinds of moulds seem to play an important part, and the production of pink and yellowish discolorations is probably due, at least in some cases, to the growth of both a *Mucor* and a mould, producing a substance having a pink appearance in alkaline or neutral reaction and a yellow one in an acid reaction.

Gueguen [2] is of the opinion that the spores causing the mildewing of fabrics are usually introduced into the fibers by the dead part of the parent cotton plant, where they have been either in a dormant or germinating state, and concludes that mildew is hardly ever due to contamination of the fabric after weaving.

The presence in the air of spores of cellulose-destroying fungi has been demonstrated by McBeth and Scales, who have isolated from plates exposed to air contamination over a dozen cellulose-destroying organisms, among which *Cladosporium herbarum* has been identified. Davis, Dreyfus, and Holland have shown that astonishingly large numbers of mould spores rain into the mill vats containing sizing materials used on the component threads, thereby becoming introduced into the woven fabric.

Tests for mildew resistance of fabrics have been in use heretofore. One, occasionally followed, is, briefly, to bury a sample of the cloth under ground at a depth of 12 to 15 ins. for a period extending over one month. The ground is kept moist by occasional watering. The condition of the fabric at the end of the test period is considered to indicate the degree of mildew resistance.

[1] U. S. Bureau of Chemistry.

[2] *Comptes rendus*, vol. 159, p. 781.

This method may give valuable information regarding the resistance of fabrics to bacterial action, but its value for determining mildew resistance is questionable. Canvas buried under ground would be subject to bacterial rather than to fungus attack. That this is so, is indicated by the fact that cotton duck coated with a thin layer of paraffin remained practically unattacked when buried under ground for nearly a month, whereas mildew developed in less than a month when inoculated in the laboratory.

Another method is to roll together several samples of the cloth to be tested with layers of fresh horse manure and of sawdust and keep for about a month in a moist condition. At the end of the period the condition of the cloth is observed, and if no deterioration is evident, the samples are again rolled up and left for another month or two.

Levine and Veitch recommend the following procedure: Cut six disks about $3\frac{1}{2}$ ins. in diameter from the sample to be tested and place in running water at room temperature for at least two days. In the absence of running water place the disks in a beaker of water and change the water several times during the day. This soaking and washing is for the purpose of removing from the fabric as much of the water-soluble, germicidal, and fungicidal substances as possible and also the fermentable material. If these are left in the fabric, they may suspend or hasten the development of the mildew spores, making it appear that the fabric is highly mildew-resistant or highly susceptible, whereas in practice the substances may be almost completely washed out by the first rain, and the resistance of the fabric become markedly different.

At the end of the period of soaking, place the disks between clean blotting papers or towels and remove excess of water by pressure. Place the disks in six bacteriological Petri plates containing 10 to 15 cc. of plain agar jelly free from nutrient matter, being careful that the plates do not become airtight. The plates with the disks are incubated in a closed chamber at a temperature of 20° to 25° C. for seven to ten days. If they show a heavy and well-developed growth, the test is discontinued. If, however, the growth of mould is entirely absent or is merely starting, the disks are inoculated with stock cultures of *Alternaria*, *Cladosporium*, and a pink *Mucor*, and further incubated for three to four weeks. The first period of incubation is designated for convenience as the " pre-inoculation period."

CHAPTER XVIII

CHEMICAL TREATMENT OF FABRICS FOR WATERPROOFING AND FLAME-PROOFING

1. Waterproofing of Fabrics.—A large variety of fabrics are now finished so as to be more or less waterproof, or, more strictly speaking, water-resistant. Fabrics of cotton, wool, silk, or of mixed fibers may be given this property.

Waterproof fabrics may be divided into two distinct classes: (1) those comprising various textures and cloths which have been treated chemically to make them water-repellent, thus preventing the passage of the moisture except under pressure. In this class the surface tension of the liquid plays an important part. (2) The second class consists of fabrics which have been coated or entirely covered with some waterproofing substance, and are impenetrable to both air and moisture.[1] Oilskins and mackintoshes are examples of this class. The first thing to be recognised in the consideration of waterproofed fabrics is that a closely constructed material is more likely to resist the percolation of the water than a loosely constructed fabric; hence the closer the weave the easier it will be to waterproof the fabric. In physical structure each wool fiber is a capillary tube, and the capillary action of these tubes explains the affinity of wool for moisture. If a wool fiber be placed under the microscope and brought in contact with a drop of water it will be found that the water is sucked up by the fiber with great avidity. To render the fiber waterproof, then, it will be necessary to fill or coat these capillary tubes with some substance insoluble in water. Subjecting the fiber to the action of superheated steam seems also to close up these capillary tubes, possibly by fusion of the cells. If the threads of yarn are also surrounded with a water-repellent substance it is possible to waterproof even loosely woven fabrics. If water is placed on fabrics thus treated it assumes the form of small spherical drops which

[1] The very best kind of waterproofing agent is one that will allow the comparatively free passage of the air and permit of the moistening of the outer surfaces of the cloth, but which opposes the passage of the water to the other side, and there are a number of colloidal precipitates which will fulfil this requirement—colloidal alumina and tin, gelatine, glue and casein, rendered insoluble by chromic acid, alum or paraffin. Colloidal alumina may be prepared from the diacetate of alumina; this in the presence of much water furnishes a hydrosol of alumina which is precipitated in a gelatinous form

may be easily shaken off and leave no trace of wetting. If, however, the water is subjected to pressure on the cloth, these spherical drops may be forced through the interstices of the fabric without really wetting the fiber at all.

W. B. Nanson (*Cotton*) states that in the waterproofing of cotton goods most of the chemical processes employed allow the goods to retain their original color, softness and suppleness, except in a few cases; if tannin, for instance, is used, the color of the fabric becomes somewhat darker but the difference is hardly noticeable in most cases. If either a bleached or unbleached fabric is waterproofed with aluminium acetate, its appearance and feel remain the same. The following substances are used more particularly for waterproofing cotton goods: Sulfate and acetate of alumina, acetate of lead, the sulfates of copper, zinc and iron, ammonium cuprate, paraffin, ceresin, wax, soap, casein, etc.

Most of the processes used for waterproofing cotton fabrics involve, to a greater or less degree, the application of the colloid theory, by the precipitation upon and in the fibers as a hydrated metallic oxide, or a tannin, in combination with some other colloid substance, as albumen, glue, casein, the fatty acids (soaps).

2. Use of Aluminium Acetate.—Waterproofing with aluminium acetate is perhaps the most common process and is in general use for waterproofing covert coatings and similar fabrics. The older method was to mix solutions of alum and sugar of lead (lead acetate) and to apply the solution to the piece by steeping or padding. The pieces after scouring and washing were hydroextracted, and without drying, the solutions were applied. The alum or double sulfate of potassium and aluminium was then replaced by aluminium sulfate, and this is in common use at the present time. A safer plan is to use a solution of aluminium acetate made by the double decomposition of aluminium sulfate and calcium acetate:

One hundred pounds calcium acetate and 700 lbs. sulfate of alumina are separately dissolved in water and brought together in a mixing vessel. The precipitate of calcium sulfate is allowed to settle, and the solution filtered through cloths or a filter press. As gray a shade of calcium acetate as possible should be chosen, as brown or black forms produce a tarry or discolored acetate which is unsuitable for proofing light-colored goods. There are three methods of application of aluminium acetate:

(I) Treatment with aluminium acetate in the padding machine for twenty minutes to half an hour, followed by tentering or drying by passing over hot cylinders. The acetic acid is evaporated off and the aluminium left on the fabric in the form of an insoluble basic acetate which is repellent to moisture.

(II) The second method of application is to pad for twenty minutes in aluminium acetate of from 3°–5° Bé. and then to after-treat another twenty minutes with a

solution of sodium carbonate, potassium carbonate, or ammonia. This precipitates the aluminium on the fabric in the form of the hydroxide which dries to the oxide on tentering.

These two methods produce a moderately waterproof article, and on account of their cheapness are generally used for low goods and unions. After wearing some time the alumina tends to appear on the surface of the cloth in the form of a white powder which may be brushed off, and the waterproof value is gradually lost.

(III) The third method, which tends to remedy these faults, is to impregnate with the acetate as before, and then after-treat with soap solution. The aluminium is thus precipitated in the form of an insoluble aluminium soap which tends to cling better to the fiber and is more water repellent than either the basic acetate or oxide. If excess of soap solution is used a "sticky" feel is imparted to the fabric. This may be remedied by passing the material through alum solution of 1°–1½° Bé.

3. Use of Fats and Waxes.—Soap solution possesses the property of emulsifying india-rubber solution, boiled oil, water glass, dextrin and other gums, and the various waxes, such as paraffin, carnaüba, Japan and beeswax. These bodies are valuable in making the cloth water-repellent and when used as adjuncts to the soap bath, they are thrown down where the alumina-impregnated fabric is passed through the solution. They adhere very tenaciously to the cloth and greatly enhance its waterproof value. Fabrics treated in this way will stand a pressure of about 12 ins., while with a simple soap bath the maximum pressure is about 2 ins.

The following is a typical example of a soap bath made up with Japan or carnaüba wax and a 10 percent solution of para rubber in oil of camphor or turpentine. The following quantities are required per pint of liquid: Soap, 1 oz.; wax, ⅞ oz.; rubber solution, 20 grains. The wax is melted and the rubber solution mixed in, and the mixture added to the boiling soap solution.

Chloro-hydrocarbon solutions of sulfonated oils are excellent for incorporating rubber and waxes into the soap solution though rather expensive.

4. Use of Gelatine and Casein.—A satisfactory waterproof cloth is obtained by padding with gelatine or casein solution and treating with a second solution to render the gelatine insoluble.[1] Substances possessing this property are formaldehyde, acetaldehyde, tannin and bichromate of potash. If aldehydes are used the gelatine may be replaced by any of the vegetable and marine gums, the majority of which form insoluble aldehyde compounds. Bichromate of potash and tannin should only be used with dark colored heavy goods, as they produce a dark brown color,

[1] Three and one-half parts of chromic oxide render 100 parts of gelatine insoluble, and it is the more stable the less it contains of free acid. It is necessary to bear in mind that chromic acid and its salts render gelatine insoluble in the presence of light, also that chromic aldehyde acts upon gelatine (or casein) either in the gaseous state or in solution. It must be remembered, however, that all waterproofing processes involving glue, gelatine or casein will render the goods stiff—to avoid this castor oil or some neutral soap must be added to the mixture to keep it soft and pliable.

and also cause light weights to stiffen. A stiff feel is generally characteristic of gelatine proofed goods, and it has to be remedied by suitable finishing. Acetaldehyde is preferable to formaldehyde in being less volatile and easier to manipulate, and also being less irritating to the noses and throats of the workpeople. Thick sacking and wagon cloths are proofed by repeated treatment with gelatine and tannin until the interstices have been filled up and the texture almost hidden. Alum solution, following up treatment with gelatine will fix the gelatine and give a moderately waterproofed cloth. In another process the fabrics are thoroughly soaked in a mixture of isinglass, alum and white soap. They are then passed through a solution of sugar of lead and dried. Glycerol is sometimes added to the gelatine solution to prevent a " stiff " feel.

A process given by Nanson is as follows: Thoroughly soak 30 lbs. (or any multiple of it) of casein in water overnight; the next morning add sufficient ammonia to the mixture to make it soluble; then add 15 lbs. of pure tallow soap in solution bringing the whole quantity of the mixture up to 50 gallons; heat this up but do not boil it. Pad the goods with this mixture on a back filling machine, spreading the casein solution on one side only and from this run the goods directly and continuously through an aging machine charged with formalin in vapor, regulating the speed so that it will take about ten minutes to run a given point through the machine. Return the goods and repeat the process, spreading the casein this time, however, on the reverse side. After this second padding and aging take the goods and run them through a cold solution of acetate of alumina at 7° Tw. and wash and dry at a cool temperature preferably in the open, or drying room.

Lowry's process of waterproofing is stated by Nanson to be one of the best; he steeps the fabric for some hours in a boiling mixture of soap, glue and water and exposes it to the air to partially dry. It is then digested for ten hours in a strong solution of alum and common salt, then washed well and dried at a low temperature about 80° F. The efficacy of this process depends largely upon the length of time used and the low temperature of the drying processes, and it is not very practical. It may be further said that additional repellency, as produced by the precipitation of fatty or resinous soaps of the various metallic oxides, is of a temporary character only and will not long remain after much wear and tear and exposure to the oxidising influence of the weather.

There are various processes by which the goods are run through mixtures of gelatine, glue, or casein and tallow soap or castor oil and alum boiled together and then heavily squeezed and dried to about 40° C. One of the simplest of these is as follows: Dissolve 36 lbs. of sulfate of alumina in 25 gallons of water. Add to this solution 61½ lbs. of acetate of lime dissolved in 25 gallons of water. Allow this to settle and decant the clear liquor; to this clear liquor add 1½ lbs. of tannic acid. Pad the goods in this and dry up, then soap in tallow soap and dry up.

The caseinate of lime method is said to insure the fabric's retaining its softness and perviousness to the air and to enable it to be washed with soap, benzine, etc., without losing its waterproofing qualities. The process is conducted as follows: Casein is mixed with about five times its weight of water, and the whole is well stirred to a creamy liquid. This is gradually mixed with a weight of slaked lime equal to about

one-fortieth of that of the casein. At the same time half the weight of the casein in soap is dissolved in twelve times its weight of water, and the soap solution is mixed with the other. The fabric is impregnated with the mixture until its weight is doubled. The fabric is next dipped in a solution of aluminium acetate at 7° Tw. (cold); this makes the caseinate of lime insoluble and forms an aluminium soap. The fabric should then be soaped, washed and dried.

5. Waterproofing Canvas.—The chief character of fabrics among cotton goods that is required to be waterproofed in canvas, which is so extensively employed for tent material, tarpaulins, wagon covers, sails, and many other uses where exposure to weather demands not only real waterproofing but also rot- and mildew-proofing. According to E. R. Clark (*Textile World*), nearly every experimenter in this field seems to have different ideas as to the best method of waterproofing this kind of canvas. As yet, practice has not become uniform, and nearly every firm has more or less different processes in use. Clark has classified the various samples which he has examined as follows:

1. The aluminium-soap processes.
2. The asphaltum, paraffin, pitch, etc., methods.
3. Processes involving the use of two layers of fabric.
4. Cuprammonium and other processes based on dissolved cellulose.
5. The drying oil methods.

6. Use of Metallic Soaps.—Several metals have been suggested for use in connection with soap to make waterproofed canvas, and also several kinds of soap. On the metallic side the aluminium compounds seem to have established themselves as the best. For the purpose basic aluminium acetate is the most frequently used salt. The use of a hard soap is desirable. Aluminium soaps made from aluminium acetate and saponified linseed oil form an especially durable impregnation. Practice in applying the aluminium soaps differs considerably. Some manufacturers soap first; others soap afterward. Widely varying concentrations have been recommended for the solutions, and there are several ideas which have been worked out as to the best method of drying. While there is no reason to state that the aluminium-soap process cannot be made to give a satisfactory canvas, the great majority of experiments along this line have been unsatisfactory. The fabrics prepared have shown a good water-repellent surface, but, on the other hand, have been found to permit the passage of water under severe conditions of service. The process has been shown to have value for clothing materials, but for actually waterproofed canvas for field service cannot as yet compete with the more recently developed methods.

7. Use of Paraffin.—All things considered, the best fabrics for this purpose have been those the waterproofing of which was accomplished

by the use of a waxy material having suitable properties as regards melting and hardening points, and permanence under the conditions of use. Asphaltum is a very good material. It can be applied melted, which is a great advantage over those materials which must be dissolved. Paraffin is widely used. The two most marked disadvantages of paraffin are its tendency to become brittle and its tendency to favor mildew growths. A paraffin of low melting-point should be used.

Rosin is frequently and disadvantageously incorporated in waterproofing compounds. It is not sufficiently stable for this use, decomposing readily in light. The decomposition of rosin is familiar in the browning of rosin-sized paper. Further, it does not seem to yield a water-repellent surface. Rosin is usually mixed with petroleum to give the desired consistency. Even wool grease has been used, although its properties seem altogether unsuitable for the purpose. Obviously the waxy matter used should be one which resists emulsification. Rubber mixed into melted paraffin makes an impregnation mixture of some value, resembling chemists' stop-cock grease. A large amount of ingenuity has been expended in producing suitable mixtures, and many of them are quite satisfactory.

Paraffin duck is the simplest of all waterproofed fabrics, and the one used in the greatest volume. A fine, firm well-woven piece of duck, well dyed and not too heavily paraffined, makes a very satisfactory fabric for many purposes, and has the merit of being lower in cost than anything else that could be described as first class. It has three marked defects, however. First, in cold weather it becomes exceedingly stiff, owing to the nature of the paraffin filling, in heavily filled goods to the point of actually cracking the cloth when it is bent, making these articles nearly unmanageable in winter weather. Second, in hot climates or in summer heat, the paraffin softens to an extent that permits it to creep or crawl along the threads of the fabric, as it has very strong capillary qualities. This results in leaks appearing in waterproofed articles, sometimes causing considerable damage. The third point is that paraffin does not protect the cotton itself against mildew. Sometimes it is believed that it actually injures the cotton, but this is not true unless it does so by breaking it on account of the stiffness in cold weather. Paraffin itself has no chemical action whatever on cotton, but it does permit mildew to grow inside cotton fabrics that are covered with paraffin on the surface, as it does not resist in any degree the growth of mildew. It is possible to so manipulate paraffin as to grow mildew freely throughout it when in flakes or powdered form.

The necessity for mildew prevention must be always considered. Rosin, in spite of the often-repeated statements in the literature to the contrary, does not prevent the growth of mildew. The canvases prepared from waxes, etc., are apt to be greasy, and these substances have the further objection of adding a great deal to the weight of the fabric. Such

processes, as has been stated, lend themselves especially easily to the process of obtaining the desired shade by incorporating pigment in the melted or dissolved mixture. Nitrogenous animal matter must be avoided.

8. Waterproofing Duplex Fabrics.—These rarely have a water-repellent surface, and usually wet through to the central coating. As regards the adhesive substance used, it must have much the same properties as the impregnation used on single fabrics. Rubberised goods, rubber-coated goods, and film-coated goods of all sorts generally are not so much waterproof in the sense that we are considering as they are coated. This distinction is usually made between "waterproofed" fabrics, or integral waterproofing, and "coated" goods, either those having the superficial faces of the goods coated with similar or dissimilar films, or those where two different fabrics each have one face coated and are then stuck together, as in the type of the familiar raincoat and automobile top fabrics known as "bonded" fabrics. In the better grades of these the outer surface may be mohair or worsted and the inner surface a cotton twill or similar fabric. The material used must not dry up in service and permit of the separation of the two fabrics. If a light fabric is used for one face, the cloth produced has a water-repellent surface which can be turned upward. The double cloths, in all probability, can be used most economically in competition with the single canvases only for such uses as truck covers. Exposed to summer sun and heat, many substances rapidly decompose, and this fact must be considered, and the stability of the adhesive used determined either by a roof test or exposure to a dye-fading lamp rich in actinic rays.

9. The Cuprammonium Process.[1]—The cuprammonium process, and other processes which depend for their effectiveness on the partial solution of the fiber, followed by precipitation as a continuous film, have been made to give very satisfactory canvases for this use. The principle of the process is rather simple, and generally understood. It is, unfortunately, very expensive, and while the fabrics prepared by it are durable and quite waterproof, it has not as yet been thoroughly proved that its advantages are sufficient to warrant its substitution for the other processes. The prices quoted have been from three to five times those quoted for the paraffin, rosin, asphaltum, etc., canvases.

One serious objection to the cuprammonium process has been that the resulting fabrics are harsh and hard to work with in the operations of

[1] This is known as the Willesden finish. The treating liquor is prepared as follows: A cold solution of sulfate of copper is precipitated with the exact amount of caustic soda necessary or slightly less. The temperature must be kept below 20° C. or the precipitate will be black instead of blue, and the leaving of a small excess of copper sulfate is an additional precaution against this. The precipitate is washed with condensed water till the washings give no precipitate or next to none, with chloride of barium. This precipitate is then pressed to get rid of most of the water, and dissolved in just enough ammonia of sp. gr. 0.93.

stitching together in the desired form for use. There is also a tendency for these fabrics to give off, in handling, an irritating dust. A very great advantage is the almost complete freedom from a tendency to mildew, secured by the retained copper. Clark has exposed samples of this kind of material to mildew spores for weeks at a time without their developing any growths at all.

10. The Drying Oil Processes.—The drying oils are in great disfavor among the purchasing agents at this time because of their tendency to spontaneous combustion and inferior permanence under the action of the various destructive agencies encountered in actual use. Some use various drying oil mixtures, and others use compounds of so-called vulcanised oils based on the reaction between various oils and gums and chloride of sulfur. Chloride of sulfur will unite with many of such compounds—linseed oil, rapeseed oil, corn oil, cottonseed oil, and so on, forming various solid, semi-solid or liquid products, some of which can be thinned with volatile solvents and compounded with fillers and colors to a consistence suitable to spread or coat. It is also possible to make thickened mixtures of the oils themselves and to vulcanise them by using a solvent or vapor carrying chloride of sulfur to the previously unvulcanised oil. Both these methods are used with various degrees of success but in most cases it has been found difficult to control the quality of the resulting product. It is by no means certain that it is practicable to attempt to secure the waterproofing of heavy canvas by the formation of a film such as the use of linseed oil and its substitutes produces. Such films almost invariably crack on repeated creasing, and show rather inferior stability in sunlight.

11. Use of Cellulose Solutions.—Solutions of cellulose acetate and pyroxylin (gun-cotton) are sometimes employed for purposes of waterproofing cotton fabrics, but neither of these is well adapted for waterproofing by saturation. However, a certain amount of the latter is used in a semi-saturated fabric for sanitary sheeting, dress shields, and similar work. The cost of these solutions renders them unsuitable for rougher classes of work and limits their use to fields where the appearance and surface of the materials, or their ability to imitate other more expensive material, is more important than the actual waterproofing or protection of surfaces.

Pyroxylin solutions are extensively employed for the coating of fabrics in the production of artificial leathers, which are now so widely used for a variety of purposes. Solutions of cellulose acetate have been successfully applied to the coating of aëroplane fabrics, as they give a very flexible yet hornlike coating that is very desirable on this class of material.

12. Electrolytic Method of Waterproofing.—A rather recent yet very successful method of waterproofing all kinds of fabrics consists in the electrolytical precipitation of an aluminium soap on the fiber. The

fabric to be treated is first impregnated with a solution of sodium oleate [1] and is then passed through a bath of aluminium acetate through which an electric current is passing. The electrolysis of the aluminium acetate solution in the presence of the fiber containing the sodium oleate causes an electro-osmosis of the waterproofing agent which is supposed to penetrate into the interstices of the fiber rather than simply furnish a coating on the outside. This method, known as the Tate process, has been very successfully operated in America on a large scale on wool, silk, and cotton fabrics.[2] The machine used for this process is shown in Fig. 215. The

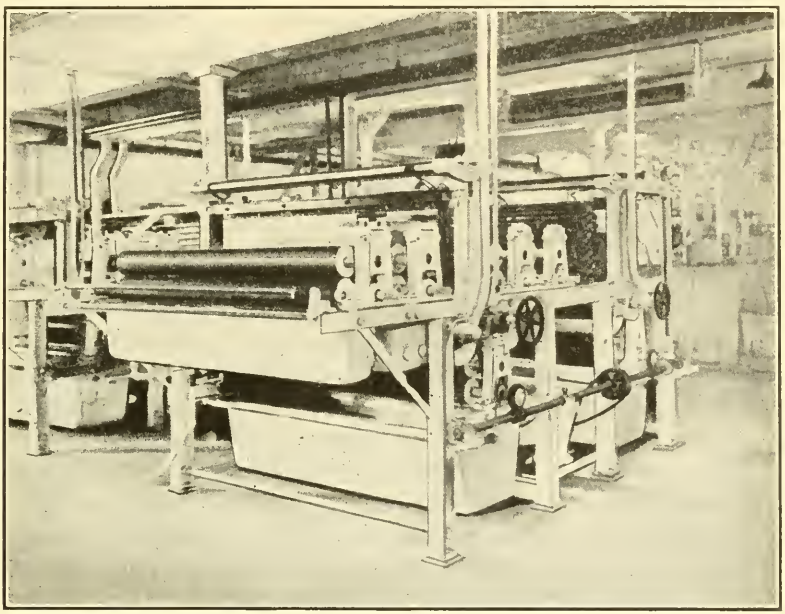


Fig. 215.—Tate Apparatus for Electrolytic Waterproofing.

fabric is first passed through a very dilute bath of sodium oleate in two tanks with squeeze rolls between. The fabric, thus impregnated with the soap solution, is then passed between the anode and cathode of the waterproofing section. The anode consists of laminated aluminium bars bolted together and covered with a heavy woolen pad. The cathode consists of eight Acheson graphite bars against which the cloth is pressed while moving through the apparatus. The solution of aluminium acetate is fed into the troughs between the graphite bars and continually trickles down through the perforations, wetting the fabric thoroughly while the

[1] Sodium palmitate and sodium stearate have also been tried, but the oleate gives the best results.

[2] See *Color Trade Journal*, 1922, p. 3.

current is passing between the electrodes and thus through the cloth. The electrolytic treatment requires a current density of 30 to 60 amperes and a voltage of 50. The waterproofing compound that is formed is a basic oleate of aluminium, and this has the special advantage of permitting the cloth to be dry cleaned without losing its water-resisting properties, which is not the case with the neutral oleate.

13. Waterproofing with Rubber Latex.—Another method of waterproofing rather recently introduced is the use of the natural rubber latex. Rubber as obtained from the trees is in the form of a milky emulsion known as latex. This latex is now imported directly, and before the separation of the insoluble rubber material it may be employed for impregnating cotton or other fabrics. The rubber is then precipitated out and vulcanised *in situ*. In this manner the fiber is not only coated with the rubber but is completely penetrated by it, forming a highly waterproof fabric. While this method has been chiefly employed in the preparation of fabrics for automobile tires, it has also been extended to the making of certain kinds of waterproof fabrics.

14. Flame-proofing of Cotton Fabrics.—The rather highly inflammable nature of cotton fabrics as compared with woolen has frequently been an obstacle to their use for many purposes. Cotton garments made from napped or fleeced cotton cloth such as flannelette has often been the cause of severe accidents owing to its inflammable nature. The same is true of the use of cotton for theatrical costumes and hangings, lace curtains, etc. It has been found possible to reduce greatly the inflammable nature of cotton by treatment of the fiber with various metallic salts. Compounds of ammonium have been largely employed for this purpose. A solution highly recommended for this purpose is composed of: 3 parts ammonium phosphate, 2 parts ammonium chloride, 2 parts ammonium sulfate, 40 parts water. The cloth may either be impregnated with this solution or the starch size may be made up with it. The volatility of these compounds when subjected to a high temperature causes a layer of inert gas to form around the fiber, and thus prevents it from flaming. Alum mixed with the sizing of cotton goods also materially reduces their liability to catch fire. Borax and sodium tungstate have also been extensively employed for the same purpose. All of these salts, however, have the bad effect of being very soluble, consequently the noninflammable property they give to the cotton is removed when the material is washed.

15. Perkin's Process.—Perkin has found that a permanent treatment may be given the cotton by impregnating the cloth with a solution of sodium stannate (45° Tw.), squeezing, drying over hot rolls, and then treating with a solution of ammonium sulfate (15° Tw.). The fabric is then dried a second time and then washed to remove the sodium sulfate

formed in the reaction, leaving in the fiber precipitated stannic oxide. This is known as the " Non-Flam " process and is the subject of a number of patents. This treatment makes the fabric quite non-inflammable, and this property is permanent against repeated washings. It also leaves the fiber soft to the feel and does not reduce its tensile strength.

The Perkin process of fireproofing has been used considerably in England, particularly for the treatment of flannelette; the considerable cost of the process, however, seems to have prevented its adoption in America. Nanson states that all goods padded with tin preparations must be heavily squeezed after passing through the liquor. Just what action this causes is not clear, but it seems that the heavy pressure increases the affinity of the cloth for the tin oxide, with the consequent deposition of more tin oxide on the goods.

16. Action of Various Salts in Fireproofing.—König[1] states that textile fabrics cannot be rendered absolutely non-inflammable, but may by suitable treatment be so changed that when exposed to a flame they do not take fire, but simply char. The various impregnating salts that are ordinarily employed act in different ways. Some volatilise at a high temperature, yielding vapors which extinguish the flame, while others melt, forming a vitreous covering for the fiber which prevents further combustion. To the former class belong the salts of ammonium, such as the sulfate. The latter salt, however, is objectionable on account of the disagreeable nature of the smoke that it generates. Ammonium chloride acts in similar manner but it is necessary to use a solution containing at least 15 percent of the salt to get good results, and of substances tried, König states this to be the worst. In the second class of salts available for flame-proofing there may be especially mentioned silicate of soda, borax, and phosphate of soda. Silicate of soda has the disadvantage of imparting to the fabric considerable stiffness, and hence cannot be applied to goods with a soft finish. Good results are obtained by the use of borax or a mixture of borax and sodium phosphate, though it is found to be better to add also some glucose to the mixture. The latter prevents the salts from crystallising on the fabric when drying and thus allows of a better penetration and impregnation. Ammonium phosphate may also be used as this combines both volatility and the vitreous melt and is said to give very good results. Other substances, such as the salts of vanadium, tungsten and molybdenum, are not volatile and do not form a melt, but they thoroughly penetrate the fiber and mineralise, as it were, without making the fabric stiff or brittle. Tungstate of soda is especially employed for fine fabrics. All of these methods, however, have the defect that the fireproofing salts are removed when the fabric is washed.

[1] Oest, *Wollen & Leinen Ind.*, 1900.

Holden [1] has studied the influence of various dyeing and mordanting operations on the combustibility of cotton goods. He finds that the presence of iron, chromium, lead or copper compounds increases the rate of burning of cotton fabrics; dyeing with substantive and sulfur colors, even when the dyed goods are after-treated with copper sulfate or chrome, exerts no appreciable influence. The following table gives the results of the various tests:

Relative Degrees of the Influence of Dyeing on the Combustibility of Cotton

Accelerating Influence.	No Appreciable Influence.	Retarding Influence.
Tannin with iron	Scoured cloth	Tannin with aluminium
Tannin with copper	Tannin alone	—
Tannin with manganese	Tannin with tin	—
Tannin with lead	Tannin with antimony	—
Tannin with chromium	—	—
Logwood with iron	Logwood alone	Logwood with aluminium
Cutch with iron	Cutch alone	Cutch with aluminium
Cutch with copper	—	—
Cutch with chromium	—	—
Fustic with iron	Fustic alone	Fustic with aluminium
Fustic with copper	—	—
Fustic with chromium	—	—
Iron buff	Substantive dyes alone	Alizarine with aluminium
Khaki	Substantive dyes coppered	—
Chrome green	Substantive dyes chromed	Alizarine with tin and aluminium
Prussiate blue	Sulfur dyes alone	—
Manganese bronze	Sulfur dyes coppered	—
Chrome yellow	Sulfur dyes chromed	—
Chrome orange	—	—
Alizarine with iron	—	—
Alizarine with chromium	—	—
Aniline black	—	—

17. Preparation of Various Fireproofing Compounds.—The various stages in the development of fireproofing may be enumerated as follows: Arfird, in 1876, recommended the saturation of cotton goods with phosphate of ammonia, but without any notable results. Fuchs, in 1820, first used water-glass (silicate of soda), and in 1821 Gay-Lussac obtained good results by its use. They observed that those chemicals which, under the action of a little heat, would melt and glaze the fibers, as with borax, for instance, were the most suitable for the purpose. Later, borate of ammonia and

[1] *Jour. Soc. Dyers & Col.*, 1918, p. 7.

phosphate of ammonia alone, or with addition of sal ammoniac, were extensively used. Morin recommended zinc oxide; Masson, the double salt of chloride and acetate of calcium. Equal parts of these two chemicals were dissolved together in warm ammonia water. Doebereiner, speaking of the easy inflammability of fabrics, mentioned borax, water-glass, alum, and phosphate of ammonia. W. H. Perkin observed that a solution of tungstate of soda, salts of alumina, and a sufficient quantity of acetic or formic acid, were very efficient in making cotton fireproof.

Perkin recommended the following proportions (parts by volume):

1.	Aluminium sulfate sol. 20° Bé.	100
	Acetic acid 7° Bé.	25
	Tungstate soda sol. 31° Bé.	200
2.	Acetate alumina 16° Bé.	100
	Acetic acid 7° Bé.	10
	Tungstate soda sol. 31° Bé.	200
3.	Aluminium sulfate 16° Bé.	100
	Acetic acid 7° Bé.	30
	Tungstate soda 33° Bé.	150
4.	Aluminium sulfate 16° Bé.	100
	Formic acid 7° Bé.	40
	Tungstate soda 33° Bé.	150

The first two ingredients are mixed, and then the tungstate is added in a thin stream, the mixture being well stirred meanwhile, so that the precipitate first formed will redissolve easily. The goods are well saturated, then allowed to lie for one hour. They are then dried, steamed, and calendered. The organic acid evaporates and leaves the insoluble precipitate of fireproofing material on the fiber.

The following processes have found wide application in actual practice:

(*a*) Thouret impregnates the goods with either 3 parts phosphate ammonia or 2 parts phosphate ammonia, 1 part sal ammoniac, and a little calcium chloride, in 45 parts of water, the different strengths being used on various grades of work.

(*b*) Nicoll takes 6 parts alum, 2 parts borax, 1 part tungstate of soda, 1 part dextrin in soapy water. Dextrin facilitates the taking-up of the salts by the fabric.

(*c*) Martin uses 8 lbs. sulfate of ammonia, 2.5 lbs. carbonate of ammonia, 30 lbs. boric acid, 2 lbs. borax, and 2 lbs. of starch in 100 liters of water. This preparation serves well for light fabrics. They are impregnated at about 100° F., then dried and pressed.

(*d*) Another good preparation is made by taking 12 lbs. alum, 4 lbs. borax, 4 lbs. phosphate of soda, 4 lbs. tungstate soda, and 2 lbs. sulfate ammonia. These are all finely powdered and mixed well. Over this mixture there is poured caustic soda lye of 36° Bé., until a milky solution results. This is boiled until it will produce a blue precipitate on a piece of wood. The goods are impregnated with this in a boiling-hot solution, then wrung or whizzed uniformly, and dried at 150° F.

(*e*) A starch for fireproofing is made as follows: 30 lbs. tungstate of s da, 30 lbs. borax, and 60 lbs. of rice or wheat starch are mixed and ground thoroughly. In using it, boil up as with ordinary starch, and apply in the usual way.

It is impossible to render textile fabrics fireproof without leaving the fireproofing composition on the fibers; although many attempts have been made to change the nature of the fiber substances, and leave it non-combustible, all efforts have been in vain. The best that can be done is to treat the fabrics with some substance which of itself is non-inflammable, and which protects the fiber substance in such a manner that it will not burst into flame when fire is near.

The following formula for a fireproofing compound for textiles has been found to prevent the fabric from bursting into flames when a treated and dried piece of lace curtain material was suspended over an alcohol lamp; the only result was that the fabric became charred and disintegrated.

Sulfate of ammonia	8 lbs.
Borax	2 "
Boric acid	3 "
Carbonate of ammonia	2 "
Dextrin	5 ozs.
Water	to make 15 gals.

The material to be " proofed " is simply immersed in the solution until thoroughly saturated, then squeezed and dried. This quantity of solution is sufficient to treat 100 lbs. of textiles.

Another, though similar, solution is prepared as follows:

Sulfate of ammonia	15 lbs.
Borax	3 "
Boric acid	3 "
Water	to make 15 gals.

The material is simply immersed until saturated, then lifted, squeezed, and dried.

A starch for sizing purposes may be made according to the following formula, and the starch may be replaced by either flour, sago, dextrin, or other similar substance.

Starch	55 lbs.
Tungstate of soda	$27\frac{1}{2}$ "
Borax	$17\frac{1}{2}$ "

For use, this compound is made into starch or size of proper consistency, applied to yarns or fabrics in the usual manner, and dried.

According to E. Duhem, the following list gives the minimum quantity of each substance required to render 100 parts of cotton flame-proof:

Reagent.	Parts by Weight.
Tungstate of ammonia	12
Sulfate of ammonia	4½
Phosphate of soda	30
Chloride of sodium (common salt)	35
Phosphate of lime	30
Phosphate of magnesia	30
Chloride of magnesium	4–5
Phosphate of zinc	20
Sulfate of zinc	4½
Borate of alumina	24
Alumina hydrate	3
Chloride of ammonium	4¼
Phosphate of ammonia	4½
Silicate of soda	50
Borax	8½
Chloride of calcium	4½
Sulfate of magnesia	15
Chloride of potassium	45
Borate of zinc	20
Phosphate of alumina	30
Boric acid	10
Silicic acid	30

The proportions and quantities vary with the kind of goods: 10 percent for delicate fabrics such as lace; 15 percent for heavy fabrics; 20 percent for buckram intended for stage curtains.

18. Effectiveness of Fireproofing Agents.—W. B. Nanson states (*Cotton*) that in studying the effects of various salts on the combustibility of textiles, it has been found that the most effective are the ammonium salts, and zinc, tin, borax, boracic acid, and aluminium, the last in the form of a precipitate of aluminate of soda with an ammonium salt. The zinc, tin, and alum in conjunction with the ammonium salts have given the best and most permanent results. The ammoniacal salts, volatilising under the influence of heat, form mixtures with the oxygen of the air and other combustible gases which are completely incombustible, the former of which combine with the fabric, while the latter forms an inert and non-inflammable atmosphere in which nothing will burn. The action of tin, aluminium, zinc, tungstates, and borates is a purely mechanical one; they simply receive, conduct, and radiate the heat, so that at no time is the fabric itself able to keep up and perpetuate its own kindling temperature, but when exposed to flame from other sources than itself, it simply smolders, blackens, and chars without bursting into flame. In other words, they are fire-resisting and slow-burning because their presence raises the kindling temperature of the fabric above that of the flame being applied to them, and with the possible exception of tin and alumina

their efficacy is short-lived. This applies to ammoniacal salts also; they either dust out or wash out, and must be renewed frequently. The oxides of tin, iron, and tungsten possess great fire-resisting possibilities but they have their limitations: tin and tungsten are expensive and iron is colored and therefore impracticable unless a buff color is permissible. Alumina, as we shall show later on, may be converted into an insoluble flame-proof compound and used with measureable success.

Peroxide of tin is applied to the cloth in the state of a soluble combination of sodium hydrate and oxide of tin, known as stannate of soda, and may be obtained by adding a solution of caustic soda to a solution of perchloride of tin, until the precipitate at first formed is entirely redissolved. If a piece of cotton cloth impregnated with such a solution is dipped in a solution of chloride or sulfate of ammonia or dilute sulfuric acid the alkaline combination of tin and soda is decomposed, and peroxide of tin is precipitated within the fiber.

The efficacy of peroxide of tin as a flame-proofing agent arises from the fact that the fiber has such a strong affinity for the tin oxide that it becomes a part of it, and the effect is thus rendered permanent; further, the tin oxide, being at its highest state of oxidation, cannot combine with more oxygen and take fire.

Another tin process is given by Nanson as follows: Steep the goods for one hour in stannate of soda at 20° Tw., squeeze heavily and dry. After drying, run through a bath composed of chloride of ammonia and acetate of zinc at 17° Tw. and dry without washing.

In the Melauny process, which is highly eulogised by the French authorities, the cotton is run through a solution of stannate of soda at from 5° to 10° Bé. and dried. It is then run through a solution of a titanium salt. Any soluble titanium salt will answer, but Nanson suggests the chloride. This solution should be so constituted that each liter may contain about 62 grams of titanium oxide. The fabric is again dried and the titanium salt is ultimately fixed by means of an alkaline bath. It is advantageous to employ, for this purpose, a solution of silicate of soda of about 12° to 15° Tw., or a mixture of tungstate of soda and ammonium chloride may be used. The fabric is afterward washed. The goods may also be treated, after the stannate, with a mixed bath containing titanium, tungsten, and a suitable solvent.

In place of stannate of soda, which is expensive as a flame-resisting agent, Nanson suggests the analogous salt of alumina. It is cheaper and its fireproofing properties are equally valuable. It has been used under the name of alumin, and, being at its highest degree of oxidation and therefore incapable of further oxidation, it cannot burn. Moreover, as it is an insoluble hydrate, it acts in a purely mechanical way by rendering the goods non-inflammable in themselves, while the subsequent treatment

with ammonium chloride, which volatilises at a red heat, affords its usual gaseous protection as explained above. Aluminate of soda, or " alumin " as it is called, may be made by dissolving powdered alum in a solution of caustic soda until it becomes saturated or until a precipitate begins to reform. The fabric is run through this at about 15° to 20° Tw., and dried; during the operation of drying the carbonic acid of the air seizes upon the caustic soda which holds the alumina in solution, causing the formation of carbonate of soda and the precipitation of the aluminium hydrate. The time consumed in drying, however, is seldom sufficiently prolonged to allow of the complete decomposition of the aluminate of soda. This is insured by afterward passing the goods through a dilute solution of chloride of ammonium, which immediately determines the complete precipitation of the alumin.

Sulfate of ammonia may be used for flame-proofing, as may also the chloride. One of the cheapest methods for rendering cotton goods flame- and spark-proof, and one which is often used on awning goods, is to pad the goods in a boiling solution composed of 60 gals. of water, 16 lbs. of acetate of lead, and 12 lbs. of sulfate of zinc, allow the goods to lie overnight in this without drying and then repeat in the morning and dry. After the goods are cooled off, run through a solution of alum, using one-half pound of alum to each gallon of water. The goods are dried up from this without rinsing. Tungstate of soda is used in the laundries of Europe on fine laces as a fireproofing agent but is expensive for commercial use and is not permanent.

One of the best ammonia compounds for fire-resisting purposes is phosphate of ammonia, which is very effective and possesses the added merit of simplicity. If a textile is steeped in a 10 percent solution of phosphate of ammonia and dried, the kindling temperature of the fabric so treated is raised to such a point that when fire is applied to it the rapid evolution of carbonic acid and ammonia renders the textile non-inflammable by the mechanical union of the phosphoric acid with the fiber. Besides producing this effect upon the fabric itself, the two gases, being incombustible, surround the fabric with an atmosphere containing no free oxygen, and consequently of a non-inflammable character. This process stiffens the goods considerably, but they become charred only and do not readily flame up when exposed to fire. This process will not stand washing or water, however.

Another process by which the phosphoric acid and ammonia may be utilised for fireproofing is by the fixation of an insoluble magnesium—ammonium phosphate precipitated on the fibers. The material is first padded in a concentrated solution of a soluble phosphate, preferably the mono-calcium salt, and dried. It is then passed through an ammoniacal solution of magnesium chloride composed of ammonia, chloride of

ammonia, and sulfate of magnesia. Ammonium phosphate is thus precipitated on, and in, the fiber, and after rinsing in a very diluted ammonic water, and drying, the material is practically non-inflammable. This property is only slightly affected by rubbing or washing. In making an ammoniacal solution of magnesium chloride it must be remembered that magnesium hydrate is soluble in a solution of chloride of ammonium, and that ammonia produces no precipitate in a solution of magnesia containing an excess of chloride of ammonia; therefore, care must be taken that sufficient chloride of ammonia is present to prevent the precipitation of the hydrate. The light rinsing after this operation in weak ammonia water serves to complete the process by precipitating any hydrate that may be uncombined with the fabric and washing off all loose particles of the hydrate.

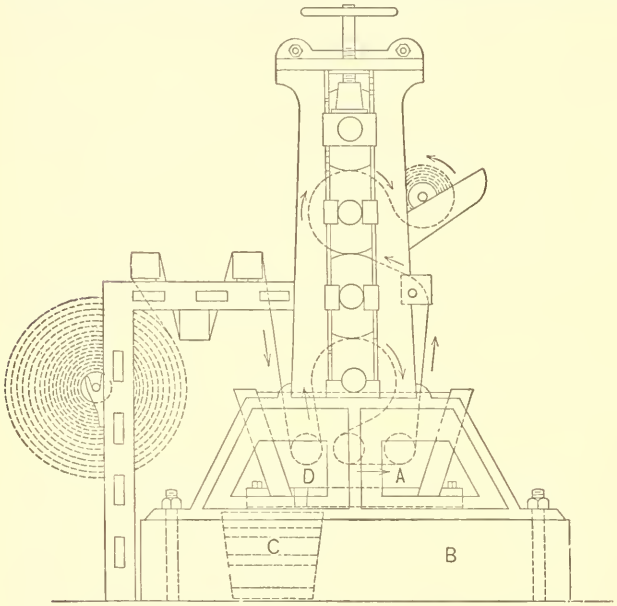


FIG. 216.—Mangle for Flameproofing Cotton Fabrics.

For rendering fabrics non-inflammable by means of starch compounds, the following mixture may be commended: 10 parts hyposulfite of soda (granulated); 10 parts cornstarch, 10 parts common salt, 5 parts borax, and 10 parts magnesium hydrate (talc). These must be well ground together so as to be thoroughly incorporated, the necessary water added according to stiffness required, and all boiled together. This is an entirely mechanical process and is not permanent.

The French Academy of Sciences has awarded a medal of honor for the following process based on the employment of salts of ammonia as a fireproofing agent, to which is added borax and boracic acid: 8 lbs. sulfate of ammonia, 2.5 lbs. carbonate of ammonia, 3 lbs. boracic acid, 8 lbs. borax, 2 lbs. starch, 0.4 lb. dextrin, and 100 lbs. of water. This is applied to the fabric at 86° F. on the mangle and dried on the dry cans.

The following is also a French recipe: 15 lbs chloride of ammonia,

6 lbs. boracic acid, 3 lbs. borax and 100 lbs. of water. Neither of the two foregoing will stand washing or water.

It will be seen from all that has been said, that the selection of the process and the agents used depend largely upon whether the goods are required to stand washing. If not, as is usually the case with lace goods, a mixture containing one or more of the following bodies may be used: metallic oxides, such as tin or alumina; compounds of ammonium, such as the chloride or phosphate; sodium phosphate, borate, silicate, tungstate, or alum.

In many cases it is only necessary to mix the materials with the dressing mixture, but where the fireproofed goods have to stand washing or outdoor wear and tear, the fireproofing again must, if possible, be precipitated on the fiber by means of a double reaction as in the recipes calling for the precipitation of tin oxide and alumina in which these oxides and hydrates are precipitated on the goods insolubly by means of a double decomposition caused by the application of ammonium and other salts.

Nanson recommends the apparatus shown in Fig. 216 for the treatment of goods to be fireproofed.

CHAPTER XIX

MERCERISED COTTON

1. Origin of Name.—Mercerising is a term applied to that process whereby cotton is treated with concentrated caustic alkalies. In its strictest significance, however, it refers most directly to the process of giving cotton a high degree of luster by subjecting its imultaneously to the chemical action of caustic alkalies and the mechanical action of tension sufficient to prevent contraction. The process is named from John Mercer, who first discovered the effect of strong solutions of caustic alkalies on cotton in the year 1844. It was not until the last decade, however, that the process attained any degree of commercial success; but during the last few years it has given practically a new fiber to the textile industry.

2. Early Development of Process.—Mercer took out a patent for the process in 1850, and he describes therein practically all the conditions of mercerising with the exception of that of tension.

Mercer's original patent is so important in connection with the treatment of cotton not only with strong solutions of caustic soda but also with other chemical reagents, that it will be of interest to give at this point the chief parts of the patent, which are as follows:

"My invention consists in subjecting vegetable fabrics and fibrous materials, cotton, flax, etc., either in the raw or the manufactured state, to the action of caustic soda or caustic potash, dilute sulfuric acid or chloride of zinc, of a strength and temperature sufficient to produce the new effects and to give the new properties which I have hereinafter described.

"The mode I adopt of carrying into operation my invention to cloth made from any vegetable fiber and bleached, is as follows: I pass the cloth through a padding machine charged with caustic soda or caustic potash of say 60° to 70° Tw., at the common temperature, say 60° F. or under, and without drying the cloth wash it in water, and then pass it through dilute sulfuric acid and wash again; or, I run the cloth over and under a series of rollers in a cistern with caustic potash or soda of from 40° to 50° Tw. at the common atmospheric temperature; the last two rollers being so set as to squeeze the excess of potash or soda back into the cisterns; the cloth then passes over and under rollers placed in a series of cisterns charged at the commencement of the operation with water only, so that at the last cistern the alkali has been nearly all washed out of the cloth; when the cloth has either gone through the padding machine or through the cisterns above described, I wash the cloth in water, pass it through dilute sulfuric acid, and again wash in water.

"When I adopt the invention to gray or unbleached cloth made from vegetable fibers, I first boil or steep the cloth in water, so as to have it thoroughly wet, and

remove most of the water by the squeezer or hydroextractor, and then pass the cloth through the soda or potash solution before described.

"I apply my invention in the same way to warps, either bleached or unbleached, but after passing through the cistern containing the alkali, the warps are either passed through squeezers or through a hole in a metallic plate to remove the alkali, and then passed through the water cistern, soured and washed as before described.

"When thread or hank yarn is operated upon, I immerse the thread or yarn in the alkali, and then wring out as is usually done in sizing or dyeing them, and afterward wash, sour and wash in water as above described.

"When cloth made from vegetable fiber, cotton, flax, etc., has been subjected to the action of soda or potash as above described, by padding, immersion, or in any other way, and then freed from alkali, the cloth will be found to have acquired new and valuable properties, the more remarkable of which I here describe. It will have shrunk in length and breadth, or have been made less in external dimensions but thicker and closer, so that by the chemical action of soda or potash I produce on cotton or other vegetable fibers effects somewhat analogous to those which are produced on wool by the processes of fulling or milling. It will have acquired greater strength and firmness, each fiber requiring greater force to break it. It will also have become heavier than it was before it was acted upon by the alkali. It will have acquired greatly augmented and improved powers of receiving colors in printing and dyeing.

"Secondly, I employ sulfuric acid diluted to 105° Tw., and at 60° F. or under. I use this acid instead of soda or potash, and operate in all respects the same as when I use soda or potash, except the last souring which is here unnecessary.

"Thirdly, when I employ solutions of chloride of zinc, instead of soda or potash, I use the solution at 145° Tw. and at 150° to 160° F., and operate the same in all respects as when I use soda or potash.

"When I operate on mixed fabrics, partly of vegetable and partly of silk, wool, or other animal fiber, such as delaines, I prefer the strength of the alkali not to be over 40° Tw. and the heat not above 50° F., lest the animal fibers should be destroyed."

Mercer further found that strong solutions of calcium chloride, stannous chloride, arsenic acid, or phosphoric acid will also induce the mercerising effect, but are less active and more troublesome than caustic alkali.

Mercer only employed the process for increasing the solidity and strength of cotton fabrics—not employing tension he did not notice very closely the increased luster. Persoz in his *Traité de l'Impression* (1846) describes a method of dyeing manganese bronze in France in which caustic soda lye of 35° Bé. was employed, and mentions that this strength was considered necessary to produce shrinkage of the fabric. The action of caustic soda on cotton, therefore, as far as contraction is concerned, seems to have been known before Mercer's discovery was patented. Garnier and Depoully in 1883 employed the process for producing crêpe by using caustic soda solutions to shrink the fabric in places. Lowe in 1890 took out an English patent describing the use of tension during mercerisation to produce a luster. The combination of Mercer's and Lowe's patents describe in detail all the necessary conditions for mercer-

ising as practised at the present time. The process of mercerising has been subject to a great number of patents, especially by Thomas and Prevost of Germany. This resulted in considerable litigation in many countries. As far as the actual chemical process itself is concerned, however, there does not appear to have been any material advance beyond the facts first discovered by Mercer and patented by him in 1850; with regard to the element of carrying out the process under tension, it may be said that this was first described and patented by Arthue Lowe in 1890, and this included the application of tension either during or after the treatment with caustic alkali. Lowe's object in stretching the material, however, was primarily to prevent the loss encountered by the shrinkage of the goods, though he does also make a specific statement that the cotton acquires an increased luster and finish by the process. The only novelty put forward by Thomas and Prevost was the use of a particular kind of cotton, that is, long-stapled varieties; but as both Mercer's and Lowe's patents claim the use of all varieties of cotton, it was difficult to see on what ground Thomas and Prevost could substantiate their claim for a patent. Patents covering the process of mercerising appear to be without foundation; though for machinery and appliances for carrying out the same such patents may be perfectly legitimate. Decisions on this matter in the United States and Germany have invalidated Thomas and Prevost's patents.

3. Essentials of Mercerising.—Mercerising, in its essential meaning relates to the action of certain chemicals on cellulose, whereby the latter is changed to a product known as **cellulose hydrate,** though, technically, the term has come to mean the process concerned with the imparting of a silk-like luster to the fiber.[1] As generally understood, it consists briefly in impregnating cotton yarn or cloth with a rather concentrated cold solution of caustic soda and subsequently washing out the caustic liquor with water, the material being either held in a state of tension during the time it is treated with the caustic alkali in order to prevent contraction, or stretched back to its original length after treatment with the alkali, but previous to washing. In either case, the material must

[1] There is much to be said both *pro* and *con* as to whether cellulose hydrate is a definite chemical compound containing water of constitution, and whether mercerised cotton is chemically different in its constitution from ordinary cotton. Wichelhous and Vieweg (*Berichte*, 1907, pp. 441 and 3880) show that there is considerable difference in the alcohol-ether solubility of the nitrates prepared from ordinary and mercerised cottons; also the latter gives a greater yield of the benzoic acid ester, and hence it is concluded that mercerised cotton is a hydrated cellulose. Schwalbe, Cross and Bevan, and Berl are also of the same opinion. These differences in reactions, however, are by no means conclusive evidences of differences in chemical constitution, for the cellulose of cotton is a complex colloidal body and its reactivity is readily affected by physical molecular changes which need not indicate definite chemical changes.

be in a state of tension during the process of washing. There are two separate phases of the mercerising process represented in the above operations which must be separately understood in order to comprehend the exact nature of the change which takes place in the appearance of the fiber; the one is the chemical action of the caustic soda, and the other is the mechanical effect brought about by the tension. The action of the caustic alkali is to effect a chemical transformation in the substance of the fiber, a further chemical reaction taking place when this product is treated with water.

Miller [1] is of the opinion that mercerised cotton does not represent a cellulose hydrate. If the material is dried at 95° C., before and after mercerisation, a slight loss of weight is recorded, instead of a gain, as a result of the treatment. The hygroscopic moisture of mercerised cotton is the same whether the sample be dried at 95° C. in an oven or at 25° C. over calcium chloride. A hydrate stable between these extremes of temperature is hardly conceivable. When dried in vacuo over sulfuric acid, mercerised cotton has the same percentage composition as cotton itself. On the other hand, mercerised cotton behaves differently from ordinary cotton in certain chemical reactions; it also shows an increased adsorption capacity for atmospheric moisture, dyestuffs, etc. From these facts Miller contends that in the process of mercerisation the sodium hydroxide enters into a state of solid solution in the cellulose and this process is accompanied by a partial conversion of the cellulose into an isomeride, the extent of this conversion depending on the concentration of the alkali.

4. Alkali-cellulose.—As previously pointed out cellulose has the property of combining with caustic soda in the ratio of $C_{12}H_{20}O_{10}$: NaOH to form a product known as alkali-cellulose, $C_{12}H_{20}O_{10}\cdot NaOH$. The formation of this compound does not appear to disintegrate the organic structure of the fiber-cell, provided the proper conditions are maintained. The alkali-cellulose, however, is apparently a rather feebly combined molecular aggregate, and does not exhibit much stability toward reagents in general. It is even decomposed by the action of water, the effect of the latter being to disrupt the bond of molecular union between the alkali and cellulose, with the consequent reformation of caustic soda and the introduction of water into the cellulose molecule. This latter substance, which may be termed cellulose hydrate, forms the chemical basis of mercerised cotton. The theory that caustic soda effects a true chemical combination with cellulose is somewhat supported by the fact that mercerised cotton undergoes chemical changes to which ordinary cotton is not susceptible. For instance, the former is much more readily dissolved by a solution of ammoniacal copper oxide; it is chemically reactive with carbon disulfide with the formation of

[1] *Berichte*, 1910, p. 3430.

soluble cellulose thiocarbonates; alkali-cellulose also reacts with benzoyl chloride and acetic anhydride, giving rise to cellulose benzoates and acetates. The nature of the chemical change in mercerised cotton, however, is rather ill defined; it no doubt can be included under that class of reactions which stands somewhat midway between ordinary physical and chemical changes, and is to be particularly observed in connection with those bodies possessing a high degree of molecular complexity, such as various colloidal substances and the large number of naturally occurring carbohydrates, starches, gums, etc. The fact that there is no evidence

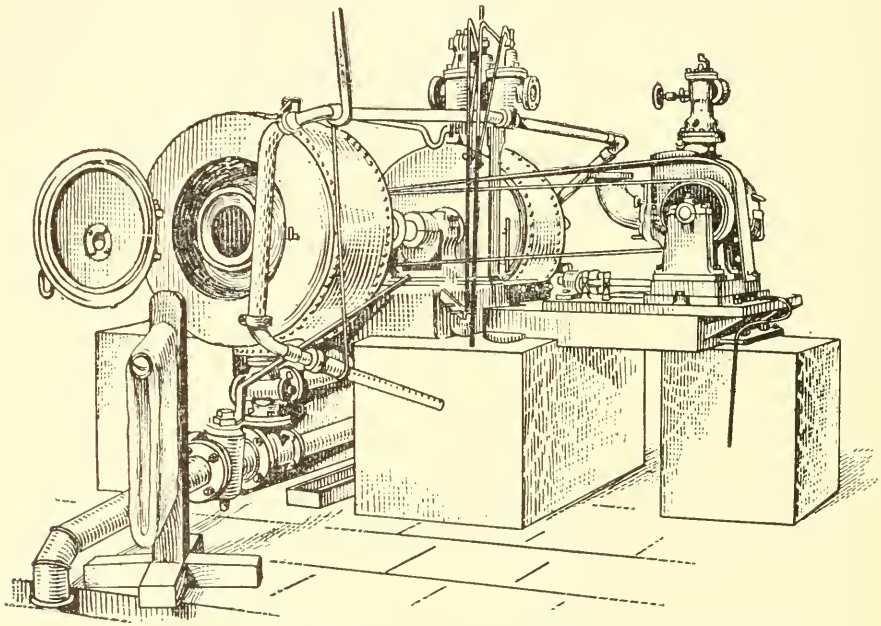


Fig. 217.—Centrifugal Skein Mercerising Machine. (Kleinewefer.)

of disorganisation in the fiber cell, as may be observed from its physical properties and microscopic appearance, is a strong argument against true chemical change, which would necessitate a rearrangement in the atomic grouping in the substance of the fiber. This would result in a decomposition of its organised structure, which would at once be manifested in a decrease in the tensile strength, and an actual breaking down of the fiber itself. But mercerised cotton shows no such change; on the other hand, its tensile strength is considerably increased, and the fiber-cell shows no tendency toward physical decomposition.

According to Schwalbe [1] the absorption curve of cotton with caustic

[1] *Berichte*, 1907, p. 3876.

soda shows two distinct points corresponding respectively to molecular ratios of

$$C_{12}H_{20}O_{10} : NaOH$$

and

$$C_{12}H_{20}O_{10} : 2NaOH.$$

Schwalbe ascribes to alkali-cellulose the formula, $C_{12}H_{19}O_{10}Na$, claiming it is a definite chemical compound capable of combining with more alkali until eventually the compound $C_{12}H_{19}O_{10}Na \cdot NaOH$ is formed.

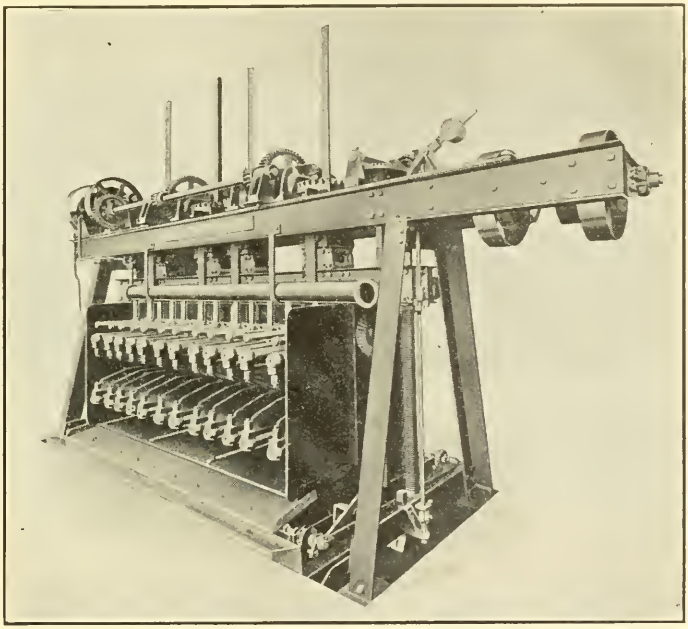


FIG. 218.—Skein Mercerising Machine. (Smith, Drum & Co.)

Alkali-cellulose is decomposed on exposure to the air by reason of the moisture and carbon dioxide combining with the alkali. Alkali-cellulose freed from soda by washing with water, that is to say, converted into hydrocellulose, has a greater affinity for substantive dyes than the alkali-cellulose washed with hot absolute alcohol. In the latter case there is no hydration of the cellulose.[1]

Washing with absolute alcohol (cold) does not decompose alkali-cellulose, and thus allows of the determination of the quantity of soda

[1] Miller, *Berichte*, 1910, p. 3430.

fixed or combined with cellulose in the case of treatment with caustic soda solutions of different degrees of concentration. Hot alcohol, however, decomposes alkali-cellulose.

Vieweg [1] has studied the absorption of caustic soda by cotton in the following manner: 3 grams of pure absorbent cotton, dried at 212° F. were immersed in 200 cc. of caustic soda solutions of different degrees of concentration. After two hours standing, 50 cc. of the liquor in each test was taken out and titrated with N/10 sulfuric acid, using phenolphthalein as an indicator. The loss in strength of the soda solution allowed a

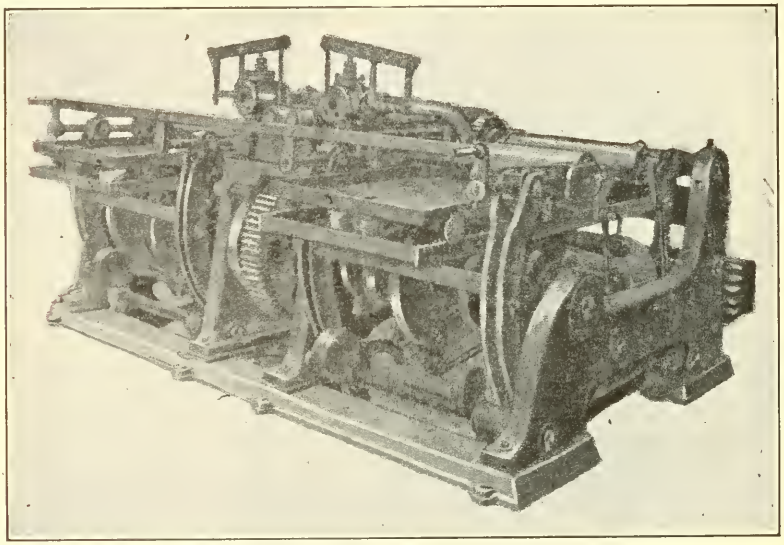


FIG. 219.—Skein Mercerising Machine. (R. J. Marx, England.)

calculation to be made as to the amount of caustic soda combined with the cotton. The following table gives the results obtained:

Concentration of caustic soda; grams NaOH per 100 cc. water	0.4	2.0	6.0	8.0	12	16	20	24	28	33	35	40
Caustic soda fixed; grams NaOH per 100 grams cotton.....	0.4	0.9	2.7	4.4	8.4	12.6	13	13	15.4	20.4	22.5	22.5

It will be noted that there are two points where the absorption becomes constant, at a concentration of about 16 percent NaOH, and again at 35

[1] *Berichte*, 1907, p. 3876.

percent NaOH. The absorption in each case would apparently correspond to alkali-cellulose compounds of $(C_6H_{10}O_5)_2 \cdot NaOH$, and $(C_6H_{10}O_5)_2 \cdot 2NaOH$, respectively.

Hübner and Teltscher [1] have also studied this question in a somewhat different manner: 10 grams of purified cotton were immersed in 600 cc. of caustic soda solutions of different concentrations for sixty-seven hours. The excess of caustic soda was then drained off and the samples were washed with absolute alcohol (cold) until no longer showing an alkaline test with phenolphthalein. The amount of combined caustic soda was then determined by ignitions.[2] The results are shown in the following table:

Grams of NaOH in 100 cc. of Liquor.	° Tw.	NaOH Retained by 100 Grams Cotton, Grams.	Times Washed with Absolute Alcohol.
0.4	1	0.190	6
2.3	5	0.198	13
4.19	10	0.330	17
8.68	20	0.710	30
9.98	23	1.456	38
11.47	26	2.752	45
13.39	30	3.250	63
15.47	35	3.298	70
17.67	40	3.600	74
20.03	45	3.184	81
22.42	50	2.722	86
27.10	60	2.824	89
31.74	70	3.030	91
36.54	80	3.024	96

With regard to the influence of salt on the action of caustic soda on cotton in mercerising, Vieweg gives the following figures showing the comparative absorptions at 20° C.:

[1] *Jour. Soc. Chem. Ind.*, 1909, p. 641.

[2] The work of Hübner and Teltscher and also that of Miller (*Chem. Zeit.*, 1905, p. 491) seems to disprove in large degree the earlier work of Vieweg and that of Gladstone in not establishing any positive evidence of the existence of a definite compound of cellulose with caustic soda. According to the investigations of Ost and Westoff (*Chem. Zeit.*, 1909, p. 198) both mercerised cellulose and the regenerated cellulose from fresh viscose, when freed from all hygroscopic water at 120° to 125° C. show the same formula as ordinary cellulose $(C_6H_{10}O_5)_n$. This would seem to argue against the view that there is a definite chemical compound between cellulose and caustic soda or that mercerised cotton represents a hydrated cellulose in which water is present as constitutional water of hydration.

Strength of the Lye, Percent.	Percentage of NaOH Absorbed.	
	From Pure Lye.	From Lye Saturated with Common Salt.
2	0.9	
4	2.7	3.8
8	4.4	6.4
12	8.4	14.5
16	11.3	17.1
20	13.2	17.4
24	12.8	18.5

Harrison points out that the action of caustic soda on cotton has been variously interpreted by different investigators as follows:

Mercer (1850) ..... $(C_6H_{10}O_5)_2Na_2O$
Thiele ..... $C_{12}H_{20}O_{12}2NaOH$
Beilstein (3rd Ed., I., 1074) ..... $2C_6H_{10}O_5NaOH$
Cross (from "Viscose") ..... $C_6H_{10}O_52NaOH$
Gladstone (*Jour. Chem. Soc.*, 17, 1862) ..... $C_{12}H_{20}O_{10}NaOH$
Crum (*Jour. Chem. Soc.*, 16, 406) ..... $C_{12}H_{20}O_{10}2NaOH$
Cross and Bevan (*Cellulose*, p. 23) ..... $C_{12}H_{20}O_{10}2NaOH$

Mercer and Gladstone deduced their formulæ from the amount of NaOH retained after treatment of cotton with caustic soda and washing with alcohol. Hübner and Teltscher carried out numerous experiments similar to those of Mercer and of Gladstone, but found no evidence of the formation of a definite compound of cellulose and caustic soda. Vieweg, in determining the amount of caustic soda absorbed by cotton at different concentrations, found two points at 16 percent and 40 percent NaOH, corresponding to the formation of two compounds, $(C_6H_{10}O_5)_2NaOH$ and $(C_6H_{10}O_5)_22NaOH$. Miller states that no compounds are formed between cellulose and caustic soda, and considers that the results of Vieweg represent a solution phenomenon. Harrison himself thinks it is highly probable that in the reaction between cotton and caustic soda, adsorption compounds are formed in a similar manner to that observed with many other colloidal substances, but as changes in the physical state of the fiber are produced by certain concentrations of soda, the ordinary adsorption formula will not be followed.

5. Physical Changes in Cotton Fiber by Mercerising.—When the cotton fiber is immersed in a concentrated solution of caustic soda it undergoes a peculiar physical modification; it appears to absorb the alkali, swelling to a cylindrical form, so that it presents more the appearance of a hair than a flat ribbon; the fiber also untwists itself and becomes much

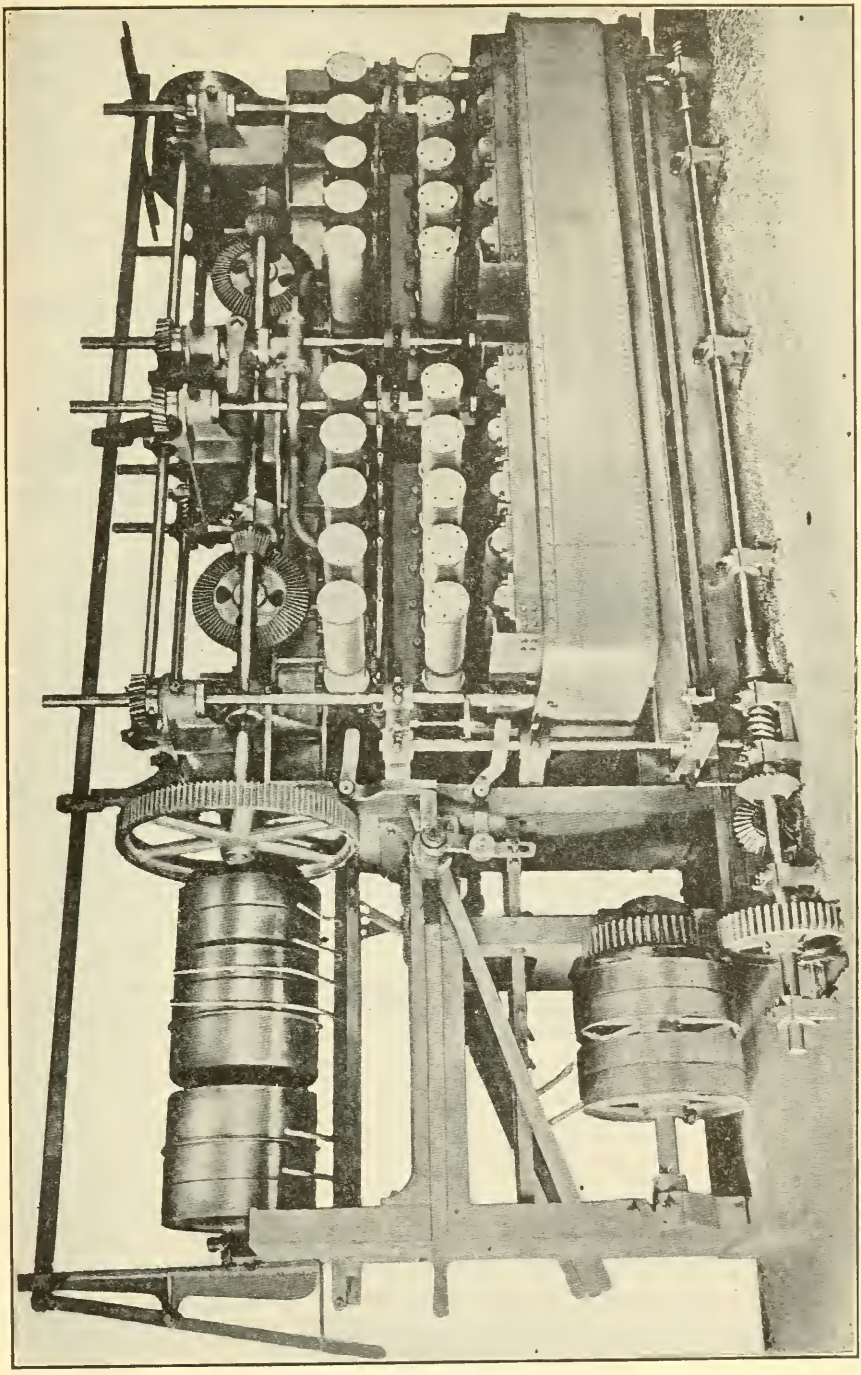


FIG. 220.—Skein Mercerising Machine, Vertical Type. (Haubold.)

straighter, at the same time shrinking considerably in length. The internal portion of the fiber acquires a gelatinous appearance, becoming somewhat translucent to light, though it is firm in structure; the surface of the fiber shows a wrinkled appearance transversely, due to a somewhat unequal distension of the inner part. There is a small degree of luster on portions of the surface, but, due to the uneven stretching and wrinkling of the external superficies, the smooth lustrous portions are irregular in occurrence and not very extensive in area. The fiber also shows a slight increase in weight.

The physical changes in the appearance of the cotton fiber when mercerised have been studied by Hübner and Pope [1] as follows:

Strength of Soda Solution.	Effect.
To 15° Tw.....	No apparent change
" 16° to 18°.....	Slight but incomplete twisting
" 20°.....	Initial untwisting followed by slow uncoiling of the twist
" 26°.....	Rapid and slow uncoiling become one, lasting 5 seconds
" 40°.....	Untwisting and uncoiling take place together
" 60° to 80°.....	Swelling precedes untwisting

6. Changes in Properties.—The changes in the physical appearance of the fiber are accompanied by a remarkable increase in the tensile strength, amounting in most cases to as much as from 30 to 50 percent; the fiber also acquiring a greater power of absorption toward many solutions, most notably those of dyestuffs. The increase in tensile strength is probably due to the fact that mercerising causes the inner structure of the fiber to become more solidly bound together by a filling up of the interstitial spaces between the molecular components of the cell-wall. In

FIG. 221.—Mercerised Cotton. (×350.) (Micrograph by author.)

[1] *Jour. Soc. Chem. Ind.*, 1904, p. 404.

this manner the fiber as a whole is given a greater degree of solidity; the internal strain between the cell-elements (which must be quite considerable after the drying out and shrinking of the ripened fiber) is lessened no doubt, and hence adds to the unified strength of the fiber. From the fact that the fiber shrinks in length in mercerising, it is probable that the cell-elements have contracted transversely on the collapse of the fiber canal, and, on being distended again by the action of the caustic alkali, these cell-elements become shortened longitudinally and are more tightly packed together.

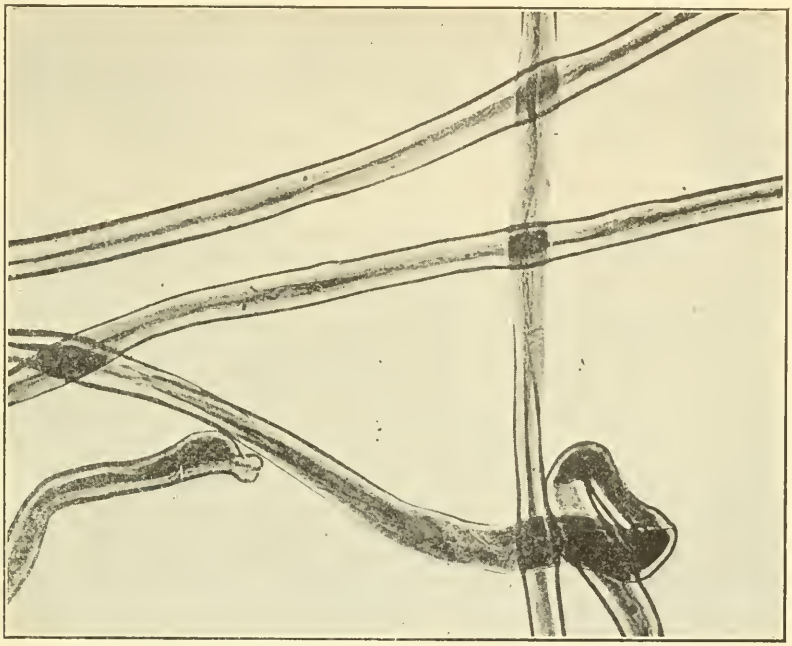


FIG. 222.—Typical Structure of Mercerised Cotton. (Herzog.)

Grosheintz gives the following results of some experiments on the effect of mercerisation on the tensile strength of cotton: Unmercerised yarn broke with a load of 356–360 grams; same yarn mercerised in cold aqueous caustic soda (35° Bé.) broke with 530–570 grams; same yarn mercerised with cold alcoholic caustic soda (10 percent) broke with 600–645 grams; same (except that hot alcoholic caustic soda was used) broke with a load of 690–740 grams.

According to Bowman [1] the increase in strength of single cotton yarns (20/1 to 60/1) by mercerisation is about 32 percent and for twofold yarns 50 percent. The yarns were mercerised without tension in cold caustic soda solution of 1.35 sp. gr., but rinsed under tension.

[1] *Structure of Cotton Fiber*, p. 227.

The increased affinity for dyestuffs exhibited by mercerised cotton is not to be considered a new inherent property of the modified cellulose induced by a change in its chemical composition. It is no doubt a result of the modified physical structure of the fiber itself; that is, when the cell-elements have become distended, like a sponge, they have a greater power of absorption and retention of liquids than when in a flattened and collapsed condition.

7. Luster of Mercerised Cotton.—The high luster imparted to cotton by mercerising is brought about by other conditions than the mere action of the caustic alkali. It has been claimed that the mercerising effect may be obtained without tension by the addition of glucose to the alkaline bath. The addition of other substances, such as ether, aluminium chloride, etc., have been claimed to produce the same result. But it is to be doubted whether a high luster is obtained by any of these methods.

In the swelling of the cell-walls and consequent contraction of the fiber, the surface remains wrinkled and uneven, due to the unequal strain of expansion. If, however, the ends of the fiber are fixed, and thus prevented from contracting when subjected to the chemical action of the alkali, the swelling of the cell-walls will cause the surface to become smooth and even, and similar to a polished surface capable of reflecting light with but little scattering of the rays. Hübner and Pope [1] have observed that in mercerising cotton the ribbon-like fiber becomes untwisted, and consider that this change of twist is of great importance in the production of the luster. They further point out that up to a concentration of 40° Tw. the swelling action of the caustic lye follows the untwisting; while at concentrations above 40° Tw. the untwisting follows the swelling. As 40° Tw. is the lowest concentration at which effective mercerisation is brought about, it is considered that the production of a luster on cotton is necessarily connected with that action of the caustic soda, causing an untwisting of the fiber to take place. Another condition which also has much to do with the production of the lustrous appearance is no doubt to be found in the physical modification of the cell elements themselves. When the fiber swells up under the action of the caustic alkali, its substance becomes gelatinous and translucent, and this has a marked effect on the optical properties of the fiber and enhances the luster considerably by lessening the proportion of light absorbed.

Dr. Frankel has advanced the opinion that the high luster exhibited by mercerised cotton is mainly due to the fiber having lost its thin cuticle during the process. But this theory is overthrown by the fact that if mercerised cotton is again subjected to the action of cold strong caustic soda, it contracts nearly as much as raw cotton would do, and loses its silky luster entirely. According to Minajeff [2] the cuticle is still present in

[1] *Jour. Soc. Chem. Ind.*, 1904, p. 404. [2] *Zeit. Färben-Ind.*, 1908, pp. 1 and 17.

both mercerised and bleached cotton. The cuticle contains as incrusting bodies, fat, wax, coloring matter, and a substance called cutin, which is insoluble in sulfuric acid. Processes in which alkaline agents are used, such as mercerising, boiling-out, and bleaching, will remove the waxy and fatty bodies, but not the cuticle itself. In some cases it is difficult to distinguish the cuticle under the microscope. Minajeff in studying the action of some reagents on the cotton fiber under the microscope arrived at the following conclusions: The cuticle of the raw cotton fiber resists treatment with concentrated cuprammonium solution, fairly strong sulfuric acid (but not the concentrated acid), and concentrated alkaline liquors both during boiling and mercerisation. The cuticle of the bleached fiber has the same properties as those of the unbleached, though not to the same extent.

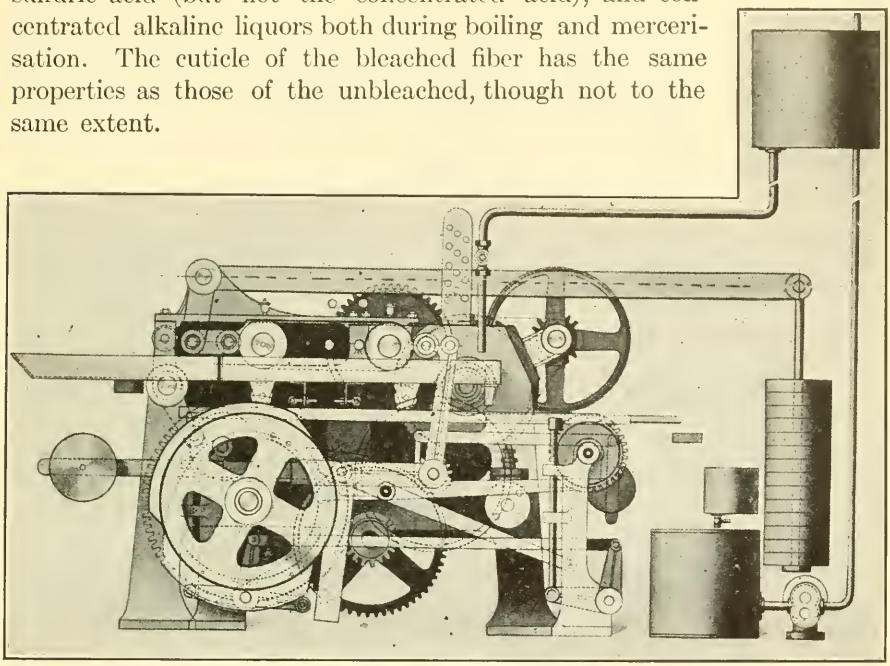


FIG. 223.—Diagram of Automatic Skein Mercerising Machine. (Hahn System.)

Hübner and Pope [1] have attributed the luster of mercerised cotton to the reflection of light from the spiral ridges on the surface of the fiber caused by the original twists in the fiber. The present author and also Lange [2] have maintained that the luster is simply due to the stretching of the surface by distension, thus producing a smooth surface which more readily reflects light. Harrison [3] also comes to this same conclusion after an exhaustive examination of the fiber by microscopic methods. If, as Hübner and Pope assert, the only difference between cotton mer-

[1] *Jour. Soc. Chem. Ind.*, 1904, p. 410.
[2] *Färber-Zeit.*, 1898, p. 197.
[3] *Jour. Soc. Dyers & Col.*, 1915, p. 202.

cerised loose and under tension lies in the absence of corkscrew-like grooves in the former, then it follows that if such grooves could be obtained in cotton mercerised loose it should possess luster. If one stretches a number of separated fibers between two holders and then mercerises them, and allows them to shrink only so far that the fibers remain straight but not under tension, then washes and dries the fibers in the holder, they will be found to possess little or no luster; but if one remercerises these same fibers without having removed them from the holder, and stretches them to their original length before washing, they will be found to be lustrous.

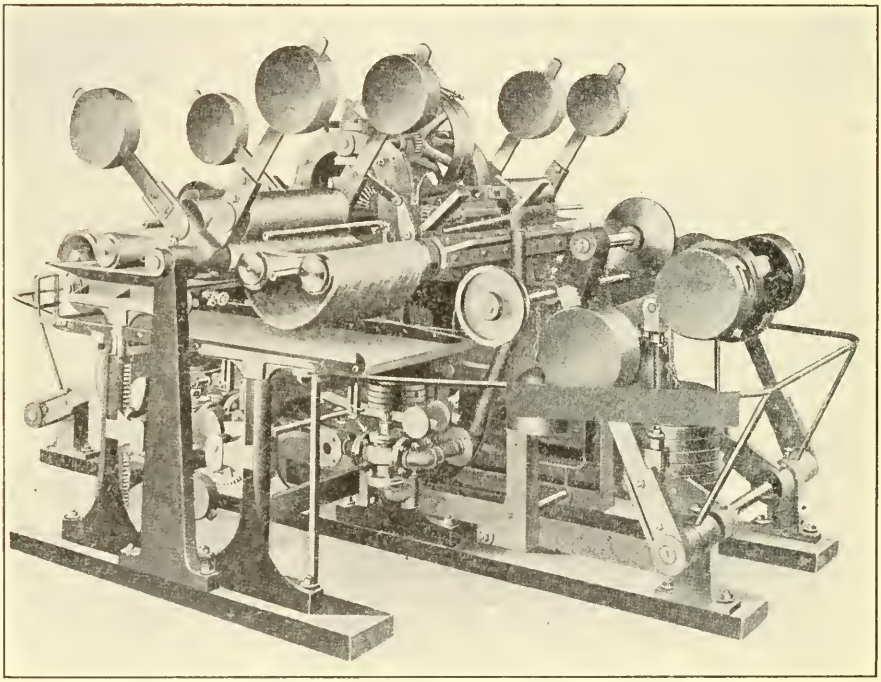


FIG. 224.—Automatic Skein Mercerising Machine. (Haubold System.)

Obviously, the number of twists per fiber will be the same in each case, and the number of twists per inch will be greater with the fibers mercerised without tension, so that these results are not in agreement with Hübner and Pope's theory.

Harrison is of the opinion that the shrinkage of the cotton fiber during mercerising is due to strains within the fiber which become active when the fiber is softened by the caustic soda.

In order to explain how this conclusion has been obtained, Harrison refers to experiments on starch. It was shown that the characteristic appearance of starch grains under polarised light is due to strains within

the grains, since the same appearance was produced in drops of gelatine by the strains set up on allowing the drops to dry, and further since the removal of the strains from starch by the solvent action of hot water removed the property of acting on polarised light. A similar result has been obtained with cotton. Under polarised light between crossed Nicols cotton fibers show strong illumination. When the fibers are treated with Schweitzer's reagent this effect disappears. Illumination persists only in the parts not completely swollen, which form the rings of the barrel-shaped formations well known to be formed with unmercerised cotton. Artificial silk made from cuprammonium solution also shows the illumination between crossed Nicols, and this is also removed when the fibers are treated with Schweitzer's reagent. A rod having strain lines running parallel to its axis when placed between crossed Nicols and turned round at right angles to its axis in a plane perpendicular to the incident light, would appear dark when parallel or at right angles to the plane of polarisation, and brightest when at 45° to the plane of polarisation. A good example of this is afforded by a strand of unvulcanised india rubber stretched when warm and fixed by cooling. Cotton fibers have been found to behave like such strained rods. The untwisting of fibers on mercerisation is most probably due to the strains being distributed partially in spiral form. The examination of fibers in polarised light affords a means of distinguishing between mercerised and unmercerised cotton. The corrugated strain lines, distinct in unmercerised cotton, are diffused in cotton mercerised without tension, and entirely missing in cotton mercerised under tension. The difference in appearance when examined at different angles to the plane of polarisation also serves for distinguishing them. The difference in the appearance of the transverse sections is very considerable.

8. Effect of Tension.—Considerable difference is to be observed in the strength and elasticity of cotton mercerised without tension and that mercerised with tension. Buntrock, in a research on this subject, found that cotton yarn mercerised without tension showed an increase of 68 percent in its tensile strength, whereas the same cotton mercerised under tension gave an increase of only 35 percent. With respect to the elasticity of the yarn, the same chemist ascertained that the untreated cotton employed in his experiments stretched 11 percent of its length before breaking; the amount for cotton mercerised without tension was 17 percent, an increase of 54 percent; cotton mercerised under tension showed no increase in elasticity at all, and could only be stretched the original 11 percent before breaking. These figures, of course, are not absolute for all varieties of cotton, but will vary within considerable limits, depending upon the character of the raw cotton employed. Attention must also be drawn to the fact that the figures for the tensile strength and elasticity

quoted above were obtained by using spun yarn and are not based on the single fiber. Of course it is the strength of the yarn which is desired in practice, but the figure for this is not necessarily that for the fiber itself. In mercerising yarn or cloth, it must be borne in mind that the fibers shrink considerably, and in doing so become more closely knit together; therefore the increase in tensile strength, as ascertained by Buntrock, represents really the greater coherence of the fibers to one another rather than an increase in the strength of the individual fiber, because in breaking a yarn spun from a large number of fibers there is little or no actual breaking of the fibers themselves, but only a pulling apart of the latter. The same criticism also applies to a determination of the elasticity. It would, perhaps, be more scientific to determine the breaking strain and elasticity of the separate fibers rather than that of the yarn or cloth; but it may be assumed, with considerable show of reason, that these figures of Buntrock will represent a fair relation between the strength and elasticity of the individual fibers. The cause of the lesser increase in tensile strength of cotton mercerised under tension as compared with that of the same cotton mercerised without tension is to be attributed to the fact that when the shrinkage of the fiber is prevented by the application of an external force the cell tissues cannot become as compact as otherwise, and there is also an internal strain induced which lessens the ultimate strength of the fiber. This latter condition also accounts for the lack of any increase in the elasticity of the mercerised fiber; the fiber when mercerised under tension is already in a stretched or strained condition, and can hardly be expected to give the same degree of elasticity as if tension had not been applied, as a certain part of its elasticity has been used up by the stretching.

9. Effect of Mercerising on Physical Properties of Yarns.—In a study made by R. S. Thoms [1] on the effect of mercerising and bleaching on cotton yarns the following results were obtained:

	Gray.	Boiled.	Mercerised.	Mercerised and Bleached, Chloride of Lime.
Loss in weight, percent	0	5.53	4.61	3.02
Loss in length, percent	0	1.95	1.00	0.37
Mean count	16.46	17.66	17.42	17.35
Lea break, in pounds	97.0	72.41	82.19	86.41
Double thread break, in ounces	27.68	23.26	26.12	27.55
Double thread stretch, in $\frac{1}{16}$ inch	20.57	14.22	11.08	10.25
Mean turns per inch	20.18	19.88	19.57	19.99
Moisture, percent as regain	5.86	5.07	7.18	7.34

[1] *Jour. Soc. Dyers & Col.*, 1911, p. 178.

	Mercerised and Bleached, Sodium Hypochlorite.	Mercerised and Bleached, Electrolytic Bleach.	Bleached, Chloride of Lime.	Bleached, Sodium Hypochlorite.
Loss in weight, percent	3.03	3.06	5.00	4.91
Loss in length, percent	1.11	1.14	2.04	1.73
Mean count	17.02	17.02	17.35	17.45
Lea break, in pounds	87.12	85.94	17.66	79.97
Double thread break, in ounces	28.08	27.58	24.14	23.93
Double thread stretch, in $\frac{1}{16}$ inch	11.09	10.78	13.76	13.97
Mean turns per inch	20.20	20.25	20.07	20.11
Moisture, percent as regain	7.55	7.59	5.28	5.46

	Bleached, Electrolytic Bleach.	Bleached, Chloride of Lime and Mercerised.	Bleached, Sodium Hypochlorite and Mercerised.	Bleached, Electrolytic Bleach and Mercerised.
Loss in weight, percent	4.88	3.40	3.37	3.37
Loss in length, percent	1.97	0.17	0.63	0.10 gain
Mean count	17.40	17.58	17.24	17.40
Lea break, in pounds	79.78	80.28	80.47	78.28
Double thread break, in ounces	23.65	26.52	26.14	25.85
Double thread stretch, in $\frac{1}{16}$ inch	13.78	9.08	9.23	8.90
Mean turns per inch	19.89	19.91	19.32	19.59
Moisture, percent as regain	5.42	7.63	7.69	8.19

10. Theory of Mercerising Action.—The reaction between cotton and caustic soda in the mercerising process is generally considered as a chemical one. This was the opinion of Mercer himself, and was supported by Gladstone, Cross and Bevan, Beltzer and many other prominent chemists. Recently, however, Ristenpart has advanced the idea that the process of mercerisation is principally an osmotic action, and the contraction which the cotton undergoes when mercerisation is unaccompanied by tension is due to purely physical causes. The cotton fiber is surrounded by a hardened cuticle, and this acts as a dialysing membrane to induce osmotic action; when the fiber is steeped in a strong solution of caustic soda the water tends to diffuse faster from the fiber into the surrounding liquid, while the soda tends to diffuse faster into the fiber. This osmotic condition demands an increased pressure within the fiber causing it to swell. In doing this it will naturally assume a form which will give it the greatest

internal capacity for a minimum surface, hence the fiber contracts in length and tends to assume a straight cylindrical form.

Later experiments on the action of caustic soda solutions on cotton seem to disprove the opinion that there is any chemical action between the fiber and the caustic soda. Harrison [1] states that the compounds formed in the reaction between cotton and caustic soda are most probably adsorption compounds. The experiments of Hübner and Teltscher [2]

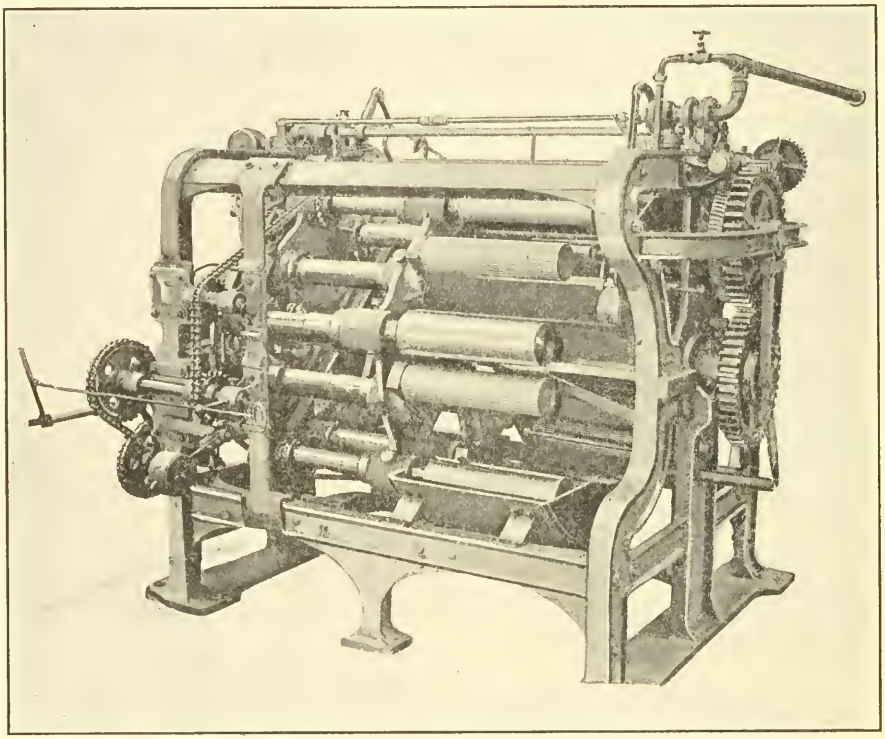


Fig. 225.—Automatic Skein Mercerising Machine, Swiss Type. (Dolder System.)

also indicate that there is no evidence of the formation of definite compounds of cellulose and caustic soda.

11. Conditions of Mercerising; Chemicals Employed.—The proper conditions for carrying into practical operation the mercerising process are simple and easily realised. Caustic soda is the most suitable and convenient reagent for bringing about the hydration of the cellulose; and it has been found that a solution of density between 60° and 70° Tw. gives the best results. Solutions of caustic potash probably give a some-

[1] *Jour. Soc. Dyers & Col.*, 1915, p. 202.
[2] *Jour. Soc. Chem. Ind.*, 1909, p. 641.

what better luster, and the shrinkage of the fiber is less than with caustic soda. But these small advantages are not sufficient to compensate for the extra expense which would be entailed by the use of caustic potash.

Caustic soda solutions of less density than 15° Tw. have but little action on cotton; the maximum effect appears to be produced by a concentration of about 60° Tw., though the difference between this and that obtained at 50° Tw. is not very marked, and even at 40° Tw. the mercerising action of the alkali is quite strong.

Vieweg[1] found that cotton absorbed caustic soda from a 16 percent solution (36° Tw.) to form a compound of the formula, $C_{12}H_{20}O_{10} \cdot NaOH$, while from solutions containing 35 percent (76° Tw.) of caustic soda the cellulose compound corresponded to the formula $C_{12}H_{20}O_{10} \cdot 2NaOH$. Hübner and Teltscher,[2] however, find that the maximum absorption of caustic soda not subsequently removed by washing with absolute alcohol, occurs at a strength of 40° Tw., while less alkali is taken up from stronger solutions; and contrary to the opinion of Gladstone and Vieweg, they find no evidence inferring the existence of soda celluloses as distinct chemical compounds.

Other reagents than caustic alkalies, however, may be employed for the hydrolysis of the cotton. Concentrated mineral acids, such, for instance, as sulfuric acid at a density of 100° to 125° Tw., will bring about the mercerising effect more or less perfectly; the same is also true of certain metallic salts, most notably the chlorides of zinc, calcium, and tin. Beyond a mere theoretical and chemical interest, however, mercerising by means of such reagents has no practical value. Mercer is his original patent describes the use of concentrated sulfuric acid, zinc chloride, and phosphoric acid as mercerising agents. Hübner and Pope[3] find that cotton yarn steeped in sulfuric acid of 114° Tw. shows a contraction of 9.5 percent. When immersed in the stretched condition a perceptible luster is obtained. A 50 percent solution of zinc chloride caused a contraction of 2.3 percent, and where acting on the stretched yarn gave a slight luster. Nitric acid of 83° Tw. caused a contraction of 9.5 percent, and when treated under tension the yarn showed some luster. Concentrated hydrochloric acid caused a contraction of 1.8 percent, and a slight degree of luster was developed under tension. A 30 percent solution of sodium sulfide caused a contraction of 1.3 percent and a slight degree of luster could be developed by stretching. In none of these cases, however, was the mercerising effect at all comparable to that obtained by the ordinary process with caustic soda.

Hübner and Pope[4] have shown that the mercerising effect may be produced with strong solutions of potassium iodide, the fiber retaining

[1] *Berichte*, 1907, p. 3876.
[2] *Jour. Soc. Chem. Ind.*, 1909, p. 643.
[3] *Jour. Soc. Chem. Ind.*, 1904, p. 409.
[4] *Jour. Soc. Chem. Ind.*, 1904, p. 404.

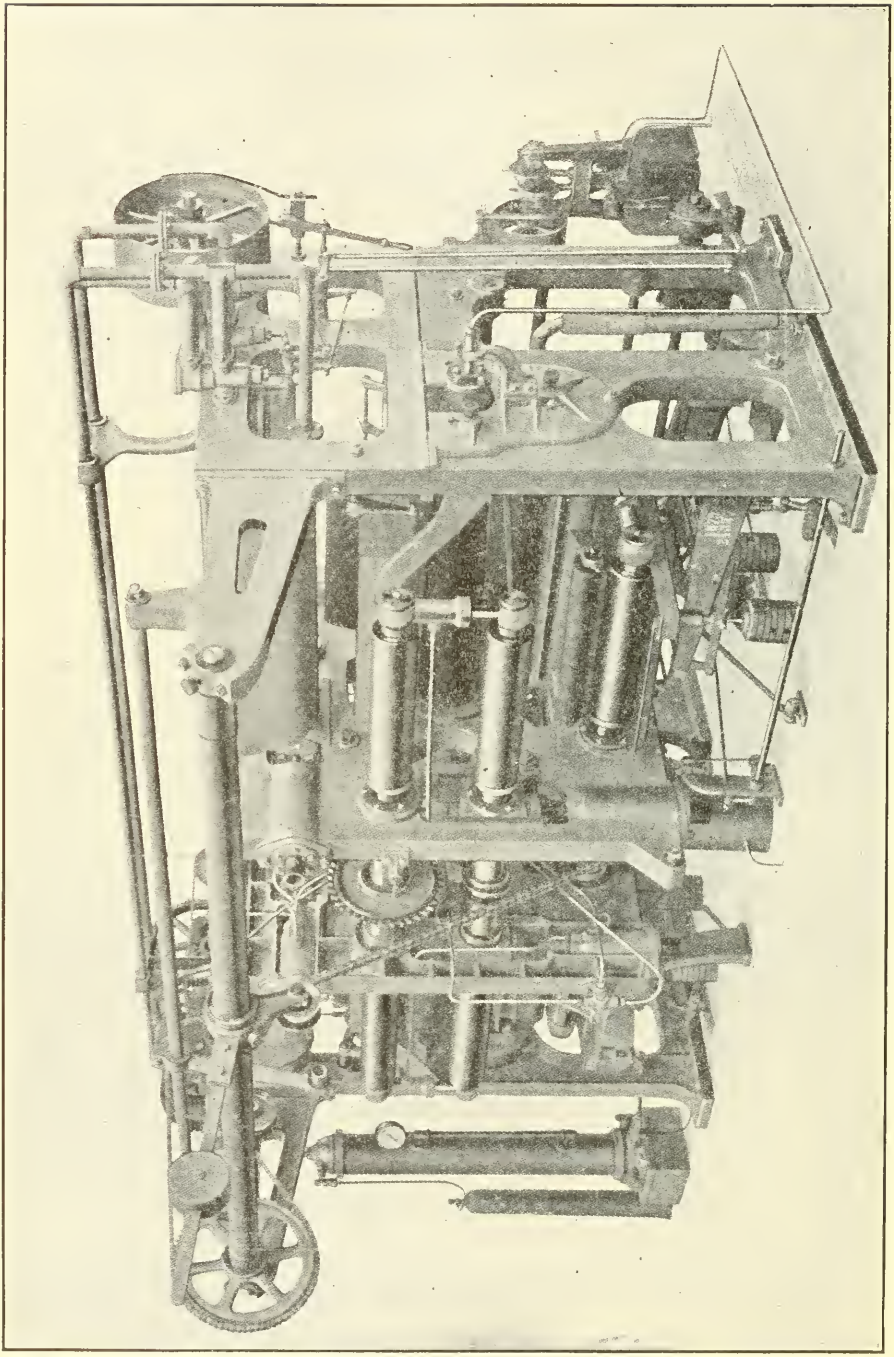


FIG. 226.—Automatic Skein Mercerising Machine, Revolving Type. (Haubold.)

15 percent of the salt and showing an increased affinity for many dyes.

The use of sulfide of sodium or potassium instead of caustic alkali has been proposed; but the process yields very poor results. It is claimed that by adding ether to the caustic soda solution good mercerisation can be obtained with but little contraction of the fiber, but as this process requires fifty parts of ether to twenty parts of caustic soda solution, the expense renders it ridiculously impracticable. It is said that the addition of carbon bisulfide to the bath of caustic soda very materially increases the luster, this causes a disintegration of the fiber, however, through the formation of viscose; hence the treatment should be very brief, otherwise the cotton will be seriously tendered. The mercerised fiber is first as stiff as horse-hair, but this effect can be removed by repeated washing. The sulfur can be removed from the cotton by washing in a solution of sal-ammoniac, and this should be done before the material is treated with an acid bath, as the latter would cause a precipitation of sulfur on the fiber and so spoil the luster.

The addition of various chemicals has been made to the caustic alkali solution with beneficial results in mercerising. It has been observed, for instance, that the addition of zinc oxide has a very marked effect. The addition of glycerol, though perhaps of some benefit in assisting in the even and thorough penetration of the liquor into the fiber, can hardly be said to appreciably modify the general operation of the alkali. Previous treatment with Turkey-red oil is also of benefit for the same reason; this is also true of such substances as sodium aluminate, and soap. The addition of sodium silicate or glycerol to the mercerising lye has been found to retard the swelling and shrinkage of the fibers, and therefore the luster obtained is inferior.[1]

A solution of caustic soda of 13° Bé. has but a slight mercerising effect, but by the addition of 1 part of zinc hydrate ($Zn(OH)_2$) to 4 parts of caustic soda (NaOH), the mercerising effect is greatly increased. The addition of ammoniacal hydrates of copper and nickel also have the same effect.

Vieweg [2] asserts that the addition of sodium chloride materially increases the absorption of caustic soda by cotton in mercerising. Miller,[3] however, states that the absorption of caustic soda by cellulose is not influenced by the presence of either sodium chloride or sodium carbonate. Hübner [4] shows that the presence of sodium chloride materially reduces the mercerising effect (shrinkage and luster) of caustic soda solution. When

[1] See Hübner and Pope, *Jour. Soc. Chem. Ind.*, 1904, p. 409.
[2] *Berichte*, 1908, p. 3269.
[3] *Jour. Russ. Chem. Phys. Gesell.*, 1905, p. 361
[4] *Jour. Soc. Chem. Ind.*, 1909, p. 228.

examined under the microscope the untwisting of the fibers is also slower and less complete. Knecht [1] has also carefully tested the effect of mercerising with and without the addition of salt, and his results show that the contraction of the fiber and the affinity for dyestuffs is lessened by the

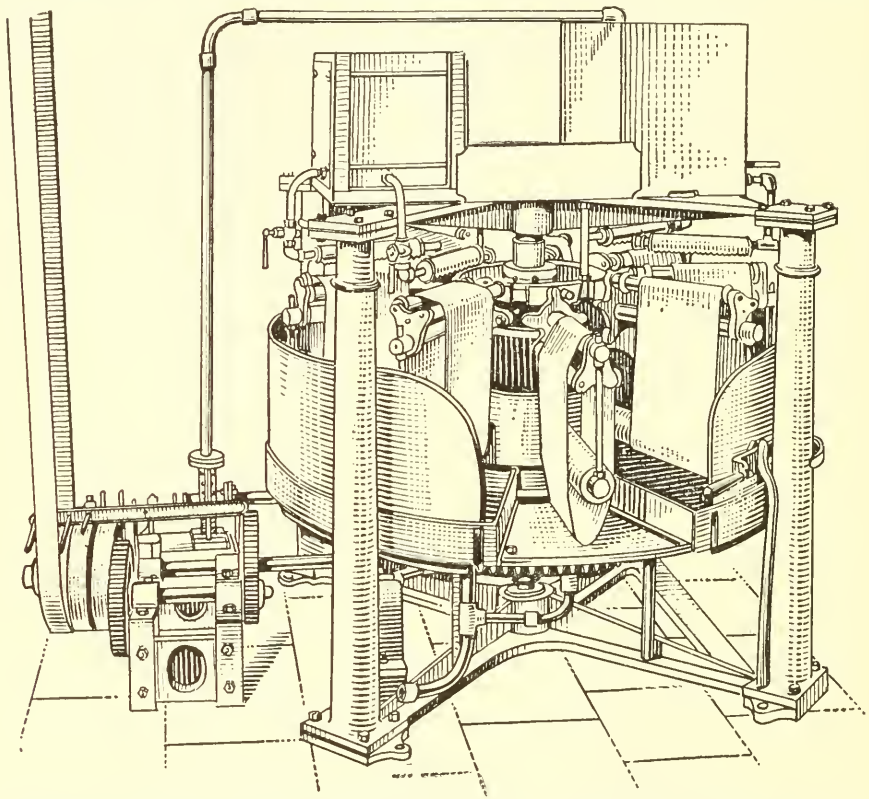


FIG. 227.—Automatic Skein Mercerising Machine; Horizontal Revolving Type. (Spencer.)

addition of salt. He gives the following table showing the quantitative absorption of several dyestuffs:

Dyestuff.	Untreated Cotton. Percent.	Mercerised with Caustic Soda Alone, Percent.	Mercerised with Caustic Soda and Salt, Percent.
Diamine Sky Blue.....	1.06	1.66	1.25
Chrysophenine.....	0.74	1.17	1.01
Benzopurpurine 4B....	1.02	1.97	1.67

[1] *Jour. Soc. Chem. Ind.*, 1909, p. 228.

It would seem therefore that Vieweg's assertion that the addition of sodium chloride to the caustic soda solution increased the mercerising effect is erroneous. It has further been demonstrated that the addition of salt to the caustic lye always decreases the luster of the mercerised cotton.

In the practical manipulation of the mercerising process it has been found that the impregnation with caustic liquor is facilitated by the addition of 5 percent of alcohol on the weight of the caustic soda.

Experiments have recently been conducted by Krais in order to determine the shrinkage which takes place in skeins of cotton yarn of various qualities when treated in the unstretched condition with mercerising solutions of caustic soda of various densities and at varying temperatures. The skeins of yarns are measured before and after treatment under a uniform tension of 2.2 lbs. Under favorable conditions with respect to the quality of the yarns, concentration of caustic soda and temperature, a maximum shrinkage of 31.3 percent is observed and this in general is somewhat higher than has been noted by previous authorities experimenting on this same problem. Experiments with single and 2-ply yarns of the same quality under similar conditions showed that the difference in shrinkage of the two was very small, although generally in favor of the single yarn. This fact becomes of interest in the mercerising of piece goods where the single filling yarn is generally brought up on the top side of the cloth. Further experiments were made on the influence of the addition of various substances to the mercerising solution. It was uniformly observed that none of these substances increases the shrinkage of the yarn and consequently did not add to the mercerising effect of the caustic soda. The substances experimented with included alcohols, various metallic salts, glycerol, dextrin, sodium carbonate, etc. In fact, all of them had the effect of reducing the percentage of shrinkage and this fact may be taken as indicating the importance of a constant control over the purity of the caustic soda solution used in the mercerising of cotton goods, especially when such solutions are used continuously, and

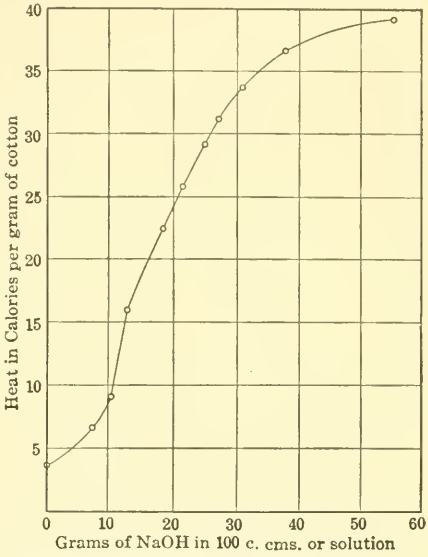


FIG. 228.—Degree of Mercerisation of Cotton as Measured by Heat Produced.

where it may thus become contaminated by the gradual formation of salts.

Fabrics of vegetable fibers (cotton or linen) may also be mercerised in patterns by printing on certain compounds capable of resisting the action of the caustic soda in the subsequent mercerising process. Resists suitable for this purpose are, in the first place, organic compounds which readily coagulate, such as albumen and casein; and, secondly, such salts, acids, or oxides which may act by neutralising the caustic alkali, or from which a hydrate may be precipitated on the fabric by its action. Such compounds, for instance, as the salts of aluminium or zinc, organic acids, and the oxides of zinc, aluminium, or chromium are quite suitable. Very beautiful effects are said to be obtainable by this process.

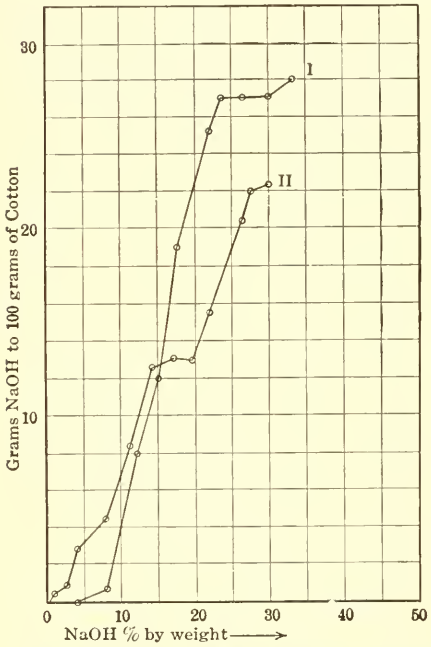


Fig. 229.—Degree of Mercerisation as Given by Mass of Caustic Soda Taken Up by Cotton: (1) Leighton; (2) Vieweg.

Barratt and Lewis[1] have endeavored to determine the degree of mercerisation of cotton by measuring the heat produced in the reaction of the caustic soda solution on the fiber. An ingenious apparatus provided with electro-thermometric device was employed. The main conclusions were that the "heat of mercerisation" of cotton by caustic soda solutions increases with the strength of the solution, but is not proportional to it. There are two inflections in the curve; the first is between 10 and 15 percent of caustic soda, indicating a rapid increase in the heat produced in that region, and this apparently corresponds to the point at which true mercerisation takes place. The other inflection is at about 30 percent of caustic soda and marks the upper limit of solutions ordinarily employed for mercerising. The following curves are given in connection with these measurements (Figs. 228, 229, and 230).

12. Temperature of Mercerising.—The temperature at which the reaction is carried out should not be higher than the usual atmospheric degree; in fact, it has been recommended to lower the temperature of the caustic soda solution by the addition of ice, but this procedure does not

[1] *Jour. Text. Inst.*, 1922, p. 113.

appear to add anything of material advantage. At elevated temperatures caustic soda appears to exert a destructive effect on cotton, probably due to the formation of oxycellulose through hydrolysis and subsequent oxidation. Beyond a certain temperature the mercerising effect rapidly diminishes, and at the boil it is scarcely appreciable. The best results appear to be obtained when the temperature is maintained at 20° C. or lower. Above this point the contraction of the fiber (which may be taken as a measure of the degree of mercerisation) grows less and less with rise of temperature.

Lefèvre [1] states that a solution of caustic soda of 35° Bé. at a low temperature gives the same mercerising effect as a solution of 50° Bé. at ordinary temperatures. Kurz considers that with raw cotton it is advantageous to use cooled solutions of caustic soda, but with bleached cotton it is not necessary, as the rise in temperature of mercerising the latter is small, whereas with raw cotton a rise in temperature of 13° to 21° C. is to be noticed.

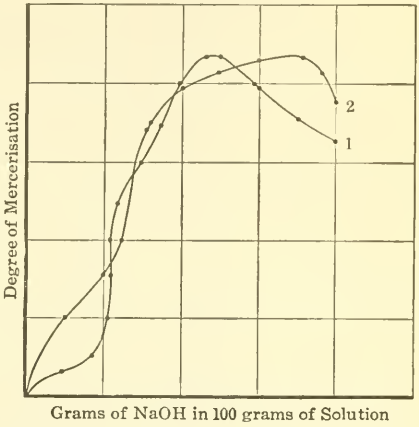


Fig. 230.—Degree of Mercerisation as Measured by: (1) Shrinkage in length of Cotton Yarn; (2) Affinity for Dyes.

In practice, it is necessary that the caustic soda solution should be maintained at a uniform density and temperature, otherwise successive lots of the mercerised material will differ in their degree of mercerisation. In the case of yarns, this unevenness may not be apparent until the material is dyed. To bring about a uniform result it is necessary to maintain a constant circulation of the caustic liquors through the mercerising machine (whatever mechanical system may be employed), adding systematically the necessary amount of strong caustic at a constant degree of density. Practice shows that a pound of cotton yarn requires from 0.5 to 0.75 lb. of solid caustic soda (98 percent NaOH) for mercerisation. As considerable heat is developed in the mercerising process, it may be necessary to employ an artificial cooling device to keep the temperature of the caustic liquor at a constant point. This is generally accomplished by passing the caustic liquor during its circulation through a tank provided with a coil of pipes supplied with cold water. It is only necessary to keep the caustic liquor below a temperature of 75° F., in order to obtain good results.

It has been found that the degree of lustering decreases very materially with the increase of temperature, as is shown graphically in the following

[1] *Rev. Gen. Mat. Col.*, 1902, p. 1.

curves (Fig. 232).[1] On examining these curves it will be noted that a characteristic phenomenon takes place when we pass from caustic soda solutions of 15° Bé. to those of 25° Bé. At a concentration of 15° Bé. the

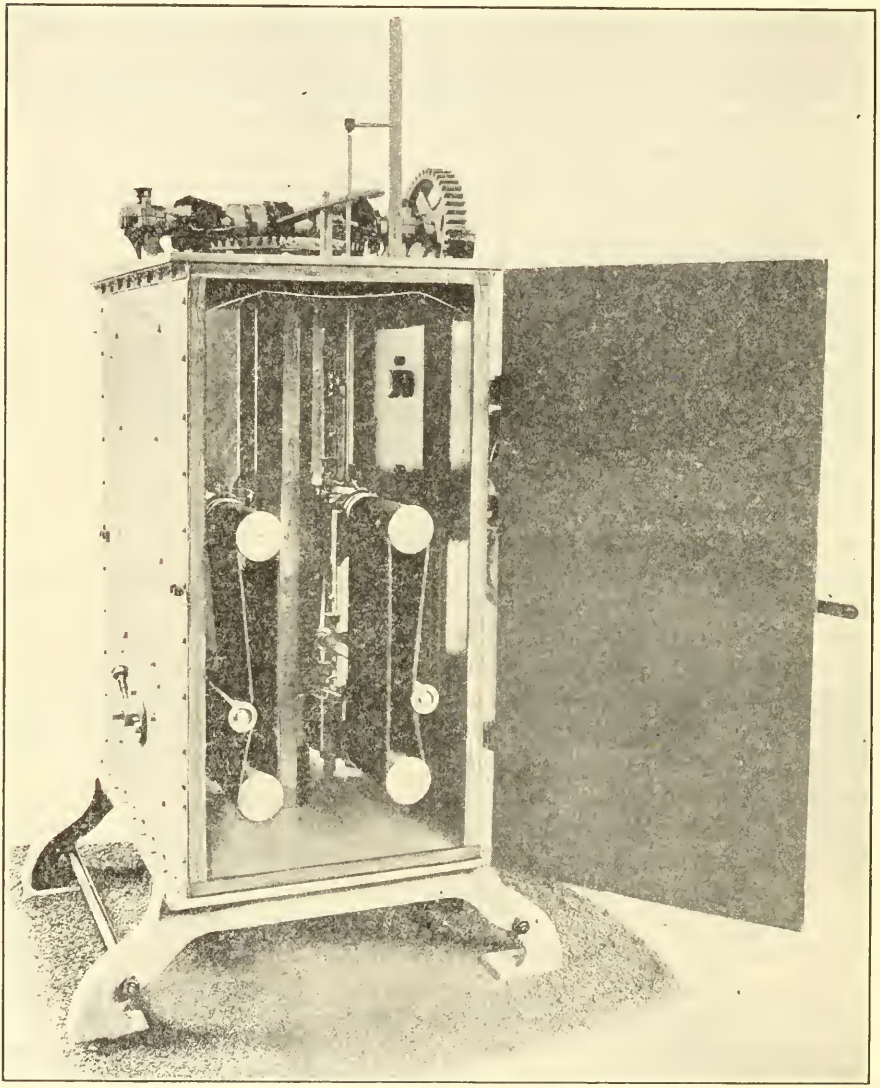


Fig. 231.—Lustering Machine for Skein Mercerised Yarn.

curve representing the contraction is convex toward the axes of the co-ordinates, whereas for concentrations over 15° Bé. the curve is concave.

[1] Beltzer, *Rev. Gen. Mat. Col.*, 1902, pp. 25 and 34.

At a certain mean concentration (20° Bé.) the curve should become a straight line.[1]

The following table[2] shows the contraction (degree of mercerisation) of cotton yarns obtained with different concentration of caustic soda and at different temperatures for periods of 1, 10, and 30 minutes. The contraction is expressed in percentages:

Temp. ° C.	Density of Caustic Soda Solutions.																	
	5° Bé.			10° Bé.			15° Bé.			25° Bé.			30° Bé.			35° Bé.		
	Duration of Mercerising in Minutes.																	
	1	10	30	1	10	30	1	10	30	1	10	30	1	10	30	1	10	30
2	0	0	0	1	1	1	12.2	15.2	16.8	19.2	20.1	21.5	22.7	22.7	22.7	23.5	23.0	23.0
18	0	0	0	0	0	0	8	8.8	11.8	19.2	20.1	21.1	22.5	22.5	22.5	23.5	23.0	21.0
30	0	0	0	0	0	0	4.6	4.6	6.0	19.2	20.3	19.0	19.8	19.8	19.8	20.7	20.5	20.1
80	0	0	0	0	0	0	3.5	3.7	3.8	13.4	13.7	14.2	15.5	15.5	15.5	15.5	15.5	15.4

A modification of the mercerising process, used not so much for the production of a luster as to give a transparent finish, is that described by Heberlein.[3] It was found that by treating cotton fabrics with caustic soda solution cooled to below 0° C., and of such concentration as would mercerise the cotton at the ordinary temperature (50° to 55° Tw.), the cotton acquires a translucent appearance which it retains even after washing and drying. The treatment is usually for one minute at a temperature of − 10° C. Pattern effects may be obtained by printing a reserve on the fabric (such as a gum thickening) and then treating with the cooled caustic soda solution. This treatment is particularly employed not so much as a process in itself, but as a preliminary process in the production of the transparent "Swiss Finish" (also known as "Permanent Finish") with concentrated sulfuric acid. The treatment with the caustic soda solution no doubt greatly increases the absorption of the acid so as to allow it to act quickly throughout the fiber. The treatment with the acid also makes the fabric permanently stiff by parchmentising the fiber, and this quality it retains even after repeated washings.

[1] Beltzer, *L'Ind. Text.*, 1908, p. 118.

[2] Gardner, *Die Mercerisation der Baumwolle.*

[3] See *Brit. Pat.* 108,671.

13. Time of Mercerising.—The mercerising action of caustic soda is rather a rapid one, as it requires only a few minutes for its completion; in fact, it appears to take place simultaneously with the impregnation of the fiber by the liquid. In ten minutes mercerisation is practically complete, and lengthening of the time does not increase the mercerising effect; in fact, too long a contact of the cotton with the caustic alkali is to be avoided, especially if the impregnated fiber is exposed to the air, as there is danger of a breaking down of the cellular structure and a consequent deterioration in the strength of the fiber. The time of immersion to produce the maximum effect also appears to be independent of both the temperature and the concentration of the alkali.

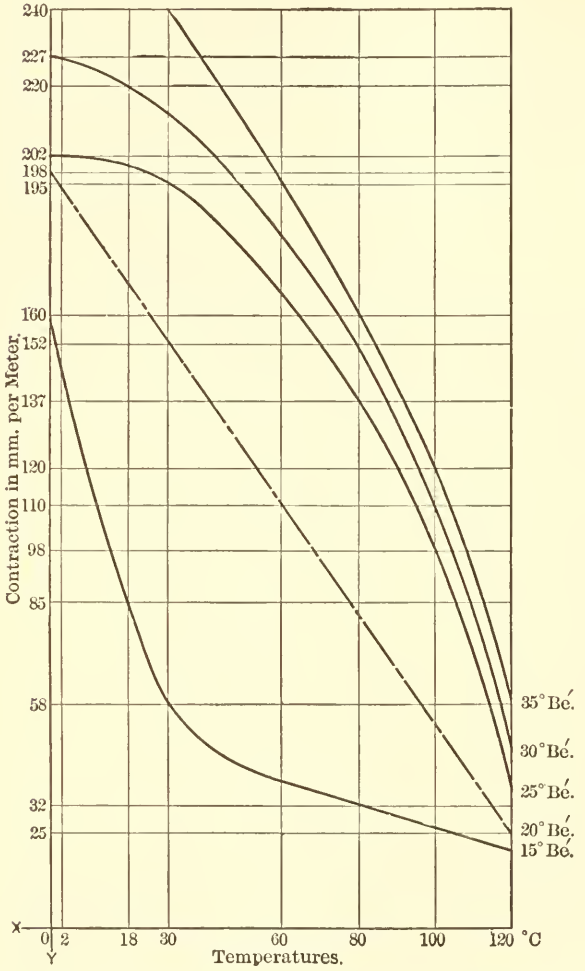


FIG. 232.—Curves Showing Contraction of Cotton Mercerised at Different Temperatures and with Different Concentrations of Alkali.

For small periods of immersion the contraction varies in proportion to the time up to about twenty seconds; the luster reaches its maximum in about this period of time.[1]

Miller [2] has established the fact that cotton absorbs less alkali after a prolonged immersion than with a shorter immersion. When 100 grams

[1] Beltzer, *Les Matières Cellulosiques*, p. 65.

[2] *Berichte*, 1907, p. 7902.

of cotton were steeped in caustic soda solution of 28° Bé. the absorption of alkali was as follows:

Time.	Alkali Absorbed, Percent
30 seconds	2.69
1 hour	2.53
24 hours	2.50

The following table shows the relations existing between the contraction of the yarn, the amount of Benzopurpurine fixed, and the duration of mercerising. The mercerising was done with caustic soda solution of 29° Bé.

Time of Mercerisation, Seconds.	Contraction, Percent.	Dyestuff Fixed, Percent.
1	15.7	3.24
10	17.4	3.62
20	25.0	3.80
40	25.0	3.89
60	25.0	3.91
120	27.0	4.10

In a detailed study of the changes undergone by single cotton fibers when treated with solutions of caustic soda, Willows, Barratt and Parker [1] have shown that the action of the caustic soda in mercerising is by no means as rapid as is commonly supposed, but nevertheless is practically complete at the end of three minutes. Solutions of less strength than 22° Tw. cause elongation, but rapid penetration and great contraction occur with solutions of 30° to 35° Tw. Solutions of 60° Tw. act very slowly, and very concentrated solutions (86° Tw.) have very little effect.

14. Tension in Mercerising.—There are two ways in which the tension may be applied in mercerising: (*a*) The material may be held in a state of tension during the time of its treatment with the caustic alkali, and until the alkali has been washed out, in which case the tension should be so maintained that the material cannot shrink; (*b*) the tension may be applied after the material has been treated with the caustic alkali, but before the latter is washed out, in which case sufficient tension should be exerted to stretch the material back to its original length. If the tension is not applied until after the alkali has been removed from the fiber, no lustering effect is produced; it is absolutely essential that the

[1] *Jour. Text. Inst.*, 1922, p. 229.

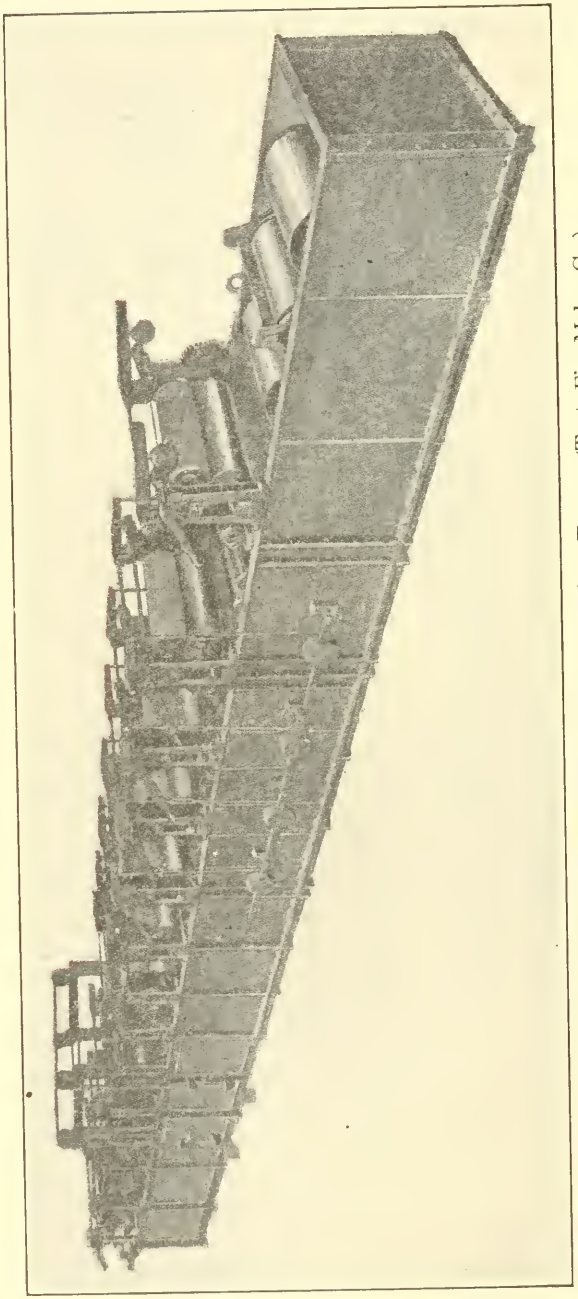


FIG. 233.—Warp Mercerising Machine, American Type. (Text. Fin. Mchy. Co.)

stretching should take place while the fiber is in the form of an alkali-cellulose, and before it has been converted by treatment with water into hydrated cellulose.

According to the experiments of Herbig, the stretching force necessary to keep the cotton in its original length during mercerisation is only from a quarter to a third of that necessary to do the stretching after mercerisation; but there appears to be no appreciable difference in the luster obtained. It would appear, however, that stretching beyond a certain point ceases to increase the luster, and to obtain the maximum lustering effect it is not necessary to stretch the cotton back to its original length. Herbig concluded that stretching during mercerisation is disadvantageous, and it is best to mercerise the yarn loose, wring it, and only stretch while rinsing, as the required stretching force is then quite small. The best time for stretching, then, is during the conversion

FIG. 234.—Warp Mercerising Installation. (Smith, Drum & Co.)

of the soda-cellulose into the hydrocellulose. If the stretching does not take place until after rinsing, almost twice the force is necessary to restore the yarn to its original length, as when in contact with the lye, and the luster is decidedly inferior. The stretching force also appears to depend on the twist, being greater in proportion as the twist is harder.

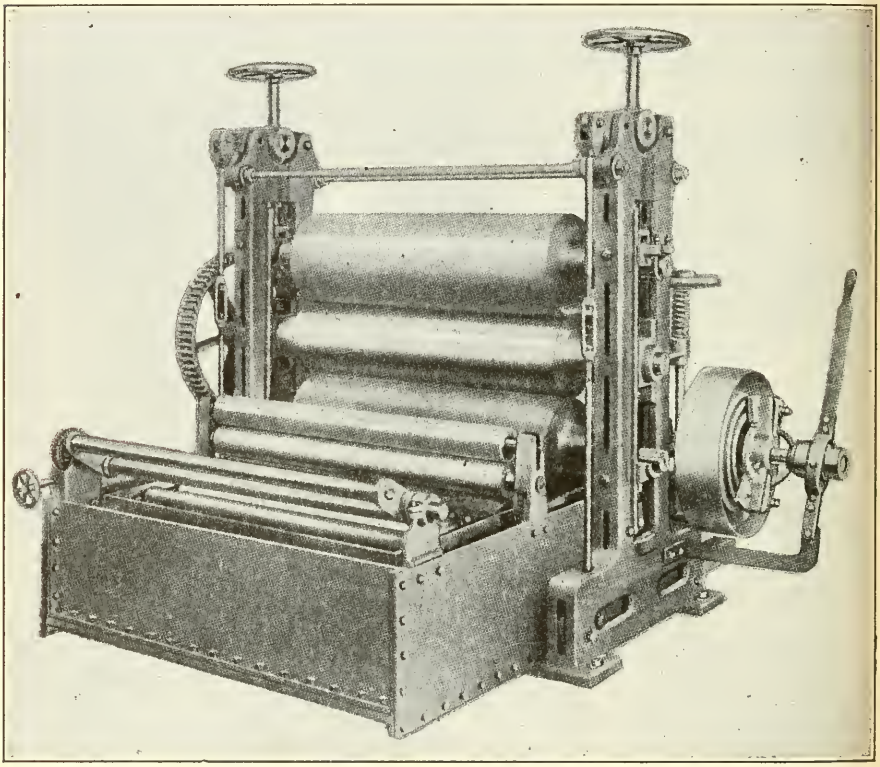


FIG. 235.—Three-roll Mercerising Padder for Piece Goods. (Text. Fin. Mchy. Co.)

Herbig gives a summary of his experimental results as follows:

1. Loose yarn mercerised without any stretching, whether long- or short-stapled, and whether with or without a hard twist, has less luster than unmercerised yarn. But even with a very slight tension the luster is greater.

2. Both with long- and short-stapled cotton the luster only becomes marked when the stretching force is sufficient to bring the yarn back to its original length.

3. Stretching beyond the original length does not give any increase in luster.

4. Considerable difference is observable in the stretching force needed between loose mercerisation followed by stretching in the lye, and keeping the cotton at its original length during mercerisation, as in the latter case only one-third to one-quarter of the force is necessary to produce the silky luster.

5. The stretching of the yarn requires only a small force when mercerised loose

and if applied when rinsing is actually in progress; for the best time for stretching is during the conversion of the soda-cellulose into hydrocellulose.

6. When rinsing is over, twice as much force is needed to restore the original length as is required for yarn still in contact with the lye; and yarns so treated contract somewhat on drying, and exhibit an inferior luster.

7. The stretching force necessary in mercerising yarn varies with the twist, and in general is greater in proportion as the twist is harder.

8. The production of the silky luster does not depend primarily on the amount of force employed in stretching, as soft yarn with only a small amount of twist can be given a luster.

9. The production of the silky luster is independent of the cotton being long- or short-stapled, as short-stapled American cotton with even a loose twist can be given a silky luster.

10. The production of a high degree of luster depends to a considerable extent on the fineness of the fiber and its natural luster. This is apparent in mercerising Sea-island and Egyptian cottons.

Grosheintz[1] conducted some interesting experiments on the contractive force exerted by cotton fabrics in mercerising. The experiments were made on pieces of cotton fabric 5 cm. wide along the filling and of such length in the warp that just 10 cm. were held between the jaws of a tensile-strength machine. The strips were fixed in such a manner as to be slightly stretched. The mercerising was affected by moistening the strips in the machine with the caustic soda solution with a glass rod. The following results were obtained with a calico:

	Tension in Kilos.	Duration of Contraction, Minutes.
1. Caustic soda 71° Tw.	5.3	4
2. Caustic soda 71° Tw., 90 cc. Water, 10 cc.	5.0	5
3. Caustic soda 71° Tw., 80 cc. Water, 20 cc.	4.2	5
4. Caustic soda 71° Tw., 70 cc. Water, 30 cc.	4.0	5
5. Caustic soda 71° Tw., 60 cc. Water, 40 cc.	3.5	5
6. Caustic soda 71° Tw., 50 cc. Water, 50 cc.	3.0	5

15. Washing as a Process in Mercerising.—By the washing of the material after steeping in caustic alkali, a twofold object is gained. In the first place, the action of the water on the alkali-cellulose is to effect a chemical transformation into cellulose hydrate, and this action is as

[1] *Bull. Soc. Ind. Mulh.*, 1902.

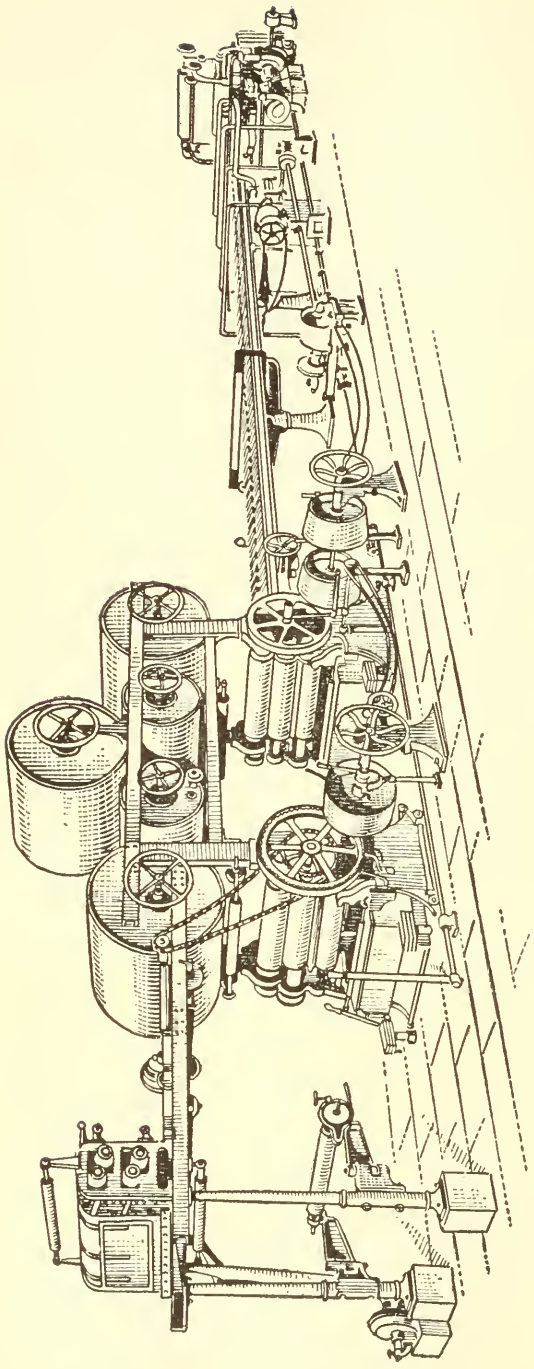


FIG. 236.—Continuous Piece Mercerising System. (Zittauer.)

really essential to mercerising as the action of the caustic soda itself. In the second place, the washing is conducted for the purpose of removing all excess of caustic alkali from the material. Caustic soda is held quite tenaciously by cotton, and it requires a very thorough and long-continued washing to remove the last traces of this compound. In order to shorten the period required for washing, it is customary to give the cotton first a rinsing in warm water, after which the tension may be relieved, and then to wash with cold water and then with acidulated water, using either sulfuric or hydrochloric acid for this purpose. The use of acetic and formic acids have also been tried, but their expense is higher than sulfuric acid. The strength of the acid bath should be so adjusted that the caustic alkali is completely neutralised without unnecessarily acidulating the cotton. To remove the excess of

acid, however, and prevent subsequent tendering of the fiber, the cotton should be thoroughly washed after treatment with the acid and finished by soaping or oiling.

When mercerised cotton is rinsed with ammonia instead of water it retains its gelatinous, parchmentlike consistency throughout the rinsing, and can be stretched to its original length without breaking. If the cotton is then rinsed with water while still stretched, the fiber regains its original appearance and acquires a luster as good as that obtained in the usual way.

16. Scrooping of Mercerised Cotton.—If the cotton is treated with a soap solution and then with dilute acetic or formic acid and dried without washing out the excess of acid, the fiber will be found to have acquired a silklike "scroop." If other acids, and especially mineral acids, are employed for washing, a subsequent rinsing with fresh water and soaping is necessary for the purpose of neutralising all of the acid, which would otherwise seriously tender the goods on drying, unless the amount of acid employed is so accurately adjusted as not to leave any free acid in the fiber.

Mercerised cotton goods that have been dyed with sulfur colors and then treated with soap and acid baths in order to impart scroop, are liable to be tendered on long storing. To avoid this the addition of sodium acetate (5 to 10 grams per liter) to the acid bath (10 grams of acetic acid per liter) has been suggested. According to an English patent No. 11,729 of 1909, a better method is to work the dyed cotton in a soap bath, hydroextract, and without washing, treat in a bath containing 17 grams of lactic acid and 7 grams of soda ash per liter for twenty minutes, hydroextract, and dry without washing.

A "scroop" may also be imparted to mercerised yarn as follows: The yarn is soaped in a lukewarm (120° F.) bath containing 8 percent of olive oil soap and 1 percent of starch (on the weight of the yarn); then hydroextracted and treated for ten minutes in a bath containing 100 gallons water, 3 lbs. tartaric acid, and 10 lbs. sodium acetate. Hydroextract and dry without rinsing.

There have been a number of methods suggested for imparting a scroop or silklike crunch to dyed hoisery, more especially when this hosiery is made up of mercerised cotton yarns. The scrooping process is carried out as a subsequent operation to that of dyeing, and is in reality a final process of finishing. The methods which have generally been suggested are those involving the use of various organic acids such as acetic, lactic, tartaric, and formic. In fact, almost any acid acting on the cotton fiber and allowed to dry will impart a silklike crunch to the material. In the case of the stronger mineral acids, such as sulfuric, hydrochloric, and nitric, the action extends too far and although a very decided silklike crunch is

developed, the cellulose of the fiber is attacked to such an extent as to cause chemical disintegration, resulting in the tendering or complete destruction of the cotton material.

The organic acids mentioned above do not have the same deleterious effect in tendering the cotton fiber, but if used alone they do not produce sufficient scroop to make the process really worth while. If, however, the organic acids are employed in connection with a soap bath, it has been found possible to produce quite a satisfactory scroop without apparent injury to the strength of the fiber. The cause of the scroop produced on cotton by this action of acids is probably a certain hardening of the surface of the fiber so that when it is bent it produces a crackling or crunching sound. This hardening may be enhanced sometimes by the use of a little glue or starch solution in connection with the acid and soap treatment, though these substances are also liable to stiffen the material. In cases where such a stiffening effect is not desired, their use would not be possible.

The character of the yarn also has considerable to do with the degree of scroop which can be produced by chemical treatment. Mercerised yarn can be scrooped to a greater degree and with more readiness than unmercerised. Soft single-ply unmercerised yarn can hardly be scrooped at all, whereas hard-twisted and lisle unmercerised yarns can be given a fair amount of scroop. The degree of scroop is also influenced by the heat used in the drying of the material. It is well to dry as hot and as quickly as possible, as these conditions will tend to harden the surface of the fiber to a greater degree and thus produce a more pronounced scrooping effect. A number of recipes for cotton, more especially mercerised cotton, have been suggested and the following includes some of these:

(1) The dyed goods are passed through a soap bath containing 1 oz. of hard soap per gallon. The goods should be worked in this soap solution until thoroughly impregnated and at the temperature of about 140° F. The goods are then removed and the excess of liquor is either squeezed out or the goods are placed in a hydroextractor and then without rinsing worked in a second bath containing $2\frac{1}{2}$ ozs. of lactic acid and 3 ozs. of caustic soda per gallon. The goods are worked in this bath for twenty minutes at a temperature of 140° F. and then hydroextracted and dried without rinsing.

(2) The soaping of the material is carried out as above described, but the second bath consists of 1 oz. of formic acid per gallon, the material being worked therein for twenty minutes at the room temperature and then hydroextracted and dried without rinsing.

(3) It is claimed that a permanent and pronounced scroop can be given to cotton by treating the material with a soap bath as above described and then giving a cold bath containing 1 oz. of tartaric acid per gallon, removing the goods after fifteen minutes, hydroextracting and drying without rinsing. A greater scrooping effect can be produced if sizing materials are added to the acid bath which may then contain 1 oz. of tartaric acid, $\frac{1}{6}$ oz. of glue and $\frac{1}{5}$ oz. potato starch. It is said that the effect can

be still further enhanced by treating the goods first with 2 to 3 percent of tannic acid and 1 to 1½ percent of antimony salt and then soaping and treating with tartaric acid as just described.

(4) According to *Ger. Pat.* 242,933, mercerised cottons may be scrooped in the following manner. The goods are first soaped as usual, squeezed out or slightly rinsed, and then treated in one of the following four baths, after which they are wrung out or hydroextracted and dried without rinsing:

(*a*) 2½ ozs. of lactic acid and 1 oz. of soda ash per gallon.

(*b*) 1 oz. of lactic acid and 2 ozs. of sodium lactate per gallon.

(*c*) 3 ozs. of tartaric acid and 2 ozs. of soda ash per gallon.

(*d*) 1 oz. of tartaric acid and ½ oz. of sodium tartrate per gallon.

In case the goods have been dyed with sulfur dyes, it is said that this process not only gives a distinct scroop but also protects the dyed material from subsequent tendering.

(5) Another process which has been suggested for the scrooping of dyed cotton material is to work in successive baths of calcium acetate, soap and acetic acid in the following general manner. Run the goods for fifteen minutes at 110° F. in a solution of calcium acetate of 7.9° Tw. Squeeze lightly but do not rinse. Then work for fifteen minutes at 120° to 140° F. in a bath containing 40 percent of soap on the weight of the goods. Again squeeze lightly or hydroextract and pass into a cold bath containing one part of acetic acid to 10 parts of water. Finally squeeze and dry without rinsing.

(6) Another process which has been suggested is the use of boric acid in the following manner: 100 lbs. of the cotton goods are worked in a bath containing 16 to 20 lbs. of boric acid for half an hour at 70° F. The goods are then hydroextracted and dried without rinsing or the effect can be enhanced by using two baths as follows: First, working the material in a solution containing 1½ ozs. of soap per gallon, hydroextracting and second passing into a bath containing 1½ ozs. of boric acid per gallon, then hydroextracting and drying without rinsing.

17. Quality of Fiber for Mercerising.—The character of the fiber employed has a considerable influence on the success of the mercerising process. From the very nature of the fact that a considerable degree of tension must be applied to the fiber during the process in order to obtain the desired luster, it would be natural to expect that the longer the staple of the fiber the more readily would it lend itself to the requirements of the operation. And such, indeed, is found to be the case; the long-stapled Sea-island and Egyptian varieties of cotton are those especially adapted for use in the preparation of mercerised cotton, while the shorter-stapled varieties are but little employed for this purpose, as the luster obtained with them is by no means as pronounced.

Besides Sea-island and Egyptian cottons, however, there are large quantities of the long-stapled American peeler cottons employed for mercerising in the United States. Certain varieties, such as the Allenseed cotton of Mississippi, are especially adapted to purposes of mercerising, and if proper care be taken in the preparation of the yarn, very good effects may be obtained. Boucart [1] gives the following reasons why only long-stapled cotton, and that only in particular counts, gives good

[1] *Rev. Gen. Mat. Col.*, 1902, p. 34.

results on mercerisation. A simple thread consists of a sort of twisted wick composed of nearly parallel fibers. The twist depends, as regards the angles it makes with the length of the thread, both upon the kind of cotton and upon the count of the yarn. Of the two sorts of simple yarns, warp-yarns have more cohesion among their elements than tensile strength, while the reverse is the case with weft-yarns. The result is that under gradually increasing tension weft-fibers slide past one another without breaking, but warp-fibers break before any such occurrence takes place. The degree of twist also depends on the mean staple, and the angle between the thread and the axis at any point is proportional to the length of the thread. The degree of twist which is required to make the cohesion exceed the tensile strength depends naturally on the strength of the fiber. The mercerising process tends to shorten each individual fiber, and this shortening is resisted by tension in the direction parallel to the axis of the

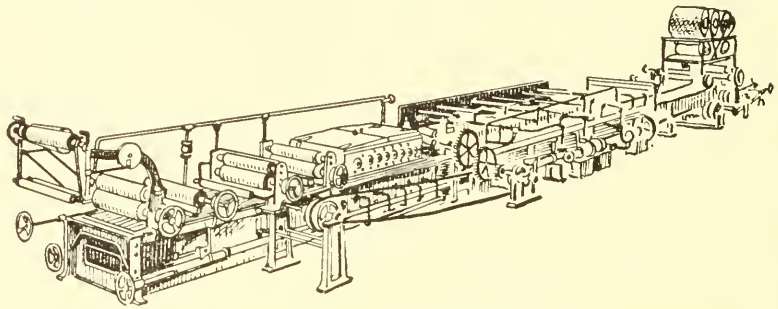


Fig. 237.—Piece Mercerising Machine with Krais Caustic Recovery System.

thread. Hence the greater the angle the thread makes with that axis the less is the effect of the tension, and if any portion of the fiber is at right angles to the axis it is not affected by the tension at all. Hence a simple warp-thread can only receive a medium amount of gloss from mercerisation, this is less as the twist is greater. Slightly twisted threads should give the best luster, but if the cohesion of the fibers is less than the contractile force exerted by the mercerising, the fibers slip past each other and no luster is produced. But if the weft-threads are fixed, as in piece goods, they take a better luster than the warp, although the latter is usually made of better cotton. Short-stapled cotton acquires a less degree of luster because it must be more tightly twisted. The best luster of all is obtained with twofold twist, in which the outer fibers lie parallel to the axis, and the yarn should be well singed to remove projecting fibers.

The quality of being mercerised is not an inherent property of any special variety of cotton, as was formerly supposed to be the case; any variety of cotton is capable of mercerisation, the essential being that the fiber shall be maintained in a state of tension. In order that this condition

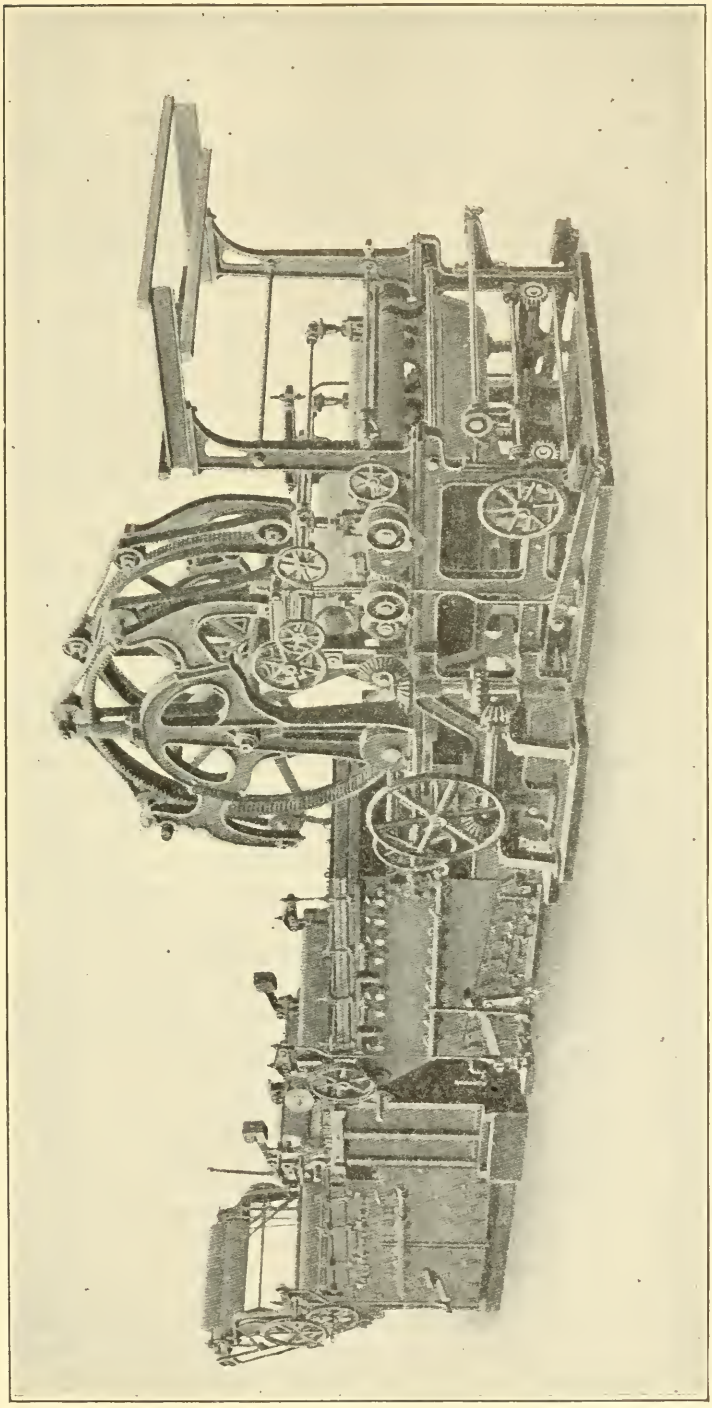


FIG. 238.—Mercerising Machine for Light Weight Cloth with Matter Caustic Recovery System.

be realised with short-stapled fibers, the yarn operated upon must be tightly twisted in order to present sufficient cohesion among the individual fibers to allow of the high tension required; this, on the other hand, prevents an even and thorough penetration of the caustic alkali into the substance of the fiber, so that, on the whole, the results obtained with short-stapled fibers are not at all comparable with those of the long-stapled varieties.

The preparation by combing of cotton for mercerisation has a considerable influence on the subsequent luster of the yarn. Sea-island cotton possesses a rather silky fiber to begin with, and this is made more adaptable to the production of a high luster by combing, in which operation the fibers are arranged parallel, and still further by gassing, which burns off the minute outer hairs. Yarns possessing considerable luster were made in this manner with fine counts of Sea-island cotton long before the discovery of lustering by mercerisation, and it was always recognised that the parallelism of the fibers so obtained by combing (and sometimes a second combing) was a great factor in the production of a silky and lustrous yarn. By later improvements in the manner of applying the tension, however, it would seem that, by realising the proper mechanical conditions, even cotton of comparatively short staple will be capable of being mercerised in a more successful manner than heretofore.

Lowe, in a study on the inter-relation of mercerisation and spinning of yarns, finds that when yarn is mercerised to "spinner's length" and washed without tension it becomes (1) more slender, (2) stronger, (3) more uniform, and (4) it receives more twist; in other words, mercerising has the effect of further spinning the yarn. In favorable cases, the increase in twist may be from 10 to 17 or 24 to 40 per inch; the increase of strength may be 14.25 percent, and the diameter may be decreased by 18 percent. The effects are due to the closer packing of the fibers in the plastic state.

18. Methods of Mercerising.—Cotton is largely mercerised both in the form of yarn and the woven fabric. Yarn mercerising may be carried out in the skein or in the warp; the latter being the favorite process in use in America, while in Europe nearly all yarn mercerising is done in the skein.[1] Machines for skein mercerising are so arranged that the

[1] The revolving type of skein mercerising machine of Kleinewefer is provided with eight pairs of rollers revolving horizontally about a central axis and requires the attention of only one operator for a production up to 2400 lbs. per day. In the first position the yarn is placed on the rollers; these move apart and give the required tension to the yarn; in the second position the caustic soda treatment is given, which is repeated in the third position; in the fourth position the yarn is squeezed and washed with the least quantity of water to provide a wash-water highly concentrated for subsequent recovery; in the fifth and sixth positions washings with warm and cold water are given; in the seventh position the yarn is soured, and finally washed again in the eighth position, where it is withdrawn from the machine.

hanks of yarn are stretched between revolving rollers and successively subjected to the action of caustic soda, a washing with warm water, and finally a washing with cold water. The operation of most forms of machines is entirely automatic.[1] In another form of apparatus the hanks are placed over a perforated horizontal drum; the latter is then revolved at a high rate of speed while the solution of caustic soda is applied from the inside and the washing with water is done in the same manner (Fig. 217). The tension in this machine is produced by the centrifugal force arising from the high speed of rotation.[2] When mercerised in the form of warps the yarn is passed continuously through a series of vats in which it is boiled-out,treated with caustic soda, washed, treated with dilute acid, and finally finished with soap. The tension is obtained by a series of squeeze-rolls. Warp mercerising is much cheaper than skein mercerising, and uniform results are more easily obtained. Cloth mercerising is carried out on an apparatus resembling a long tenter frame so that the cloth is kept in tension by a continuous series of side clamps. As the cloth moves along this frame it is subjected to the various treatments of caustic soda, washing with water, and neutralising with dilute acid. In any form of mercerising the tension may be released as soon as the strong caustic soda is removed from the cotton by washing; it is not necessary that all of the caustic soda should be removed before the tension is slackened.

Attempts have also been made to mercerise cotton in the loose state, as in the form of combed sliver. Ingenious devices have been contrived to prevent the fibers from shrinking during the process. In one form of apparatus the sliver is packed into a compact mass, and the mercerising solutions are forced through it by means of a vacuum or a pump. In another machine the sliver is placed between two perforated sheets of metal pressed tightly together, and then exposed to the successive action of caustic soda and water. A centrifugal perforated drum rotating at a high speed has also been used for mercerising cotton sliver.

Many ingenious machines have been constructed for the purpose of mercerising cotton in the loose state or in the form of combed sliver, but so far they have not proved of any practical value. An illuminating article on this subject is that of F. Erban.[3] It has been suggested by Gros and Bourcart [4] to twist the sliver into a tight thread, in which condition it is mercerised, washed and dried, after which it is untwisted

[1] A good description of the different types of machines for mercerising skein yarn is given in Herzfeld, *Das Färben und Bleichen*, vol. II, p. 373.

[2] This centrifugal mercerising machine was devised by Kleinewefer, and was once extensively used. We understand, however, that this form of apparatus has now been practically abandoned for the roller type of machine.

[3] *Monatsschrift. Text.*, 1907, pp. 349 and 390.

[4] *Ger. Pat.* 124,135; see *Zeit. Farb. Ind.*, 1902, p. 54.

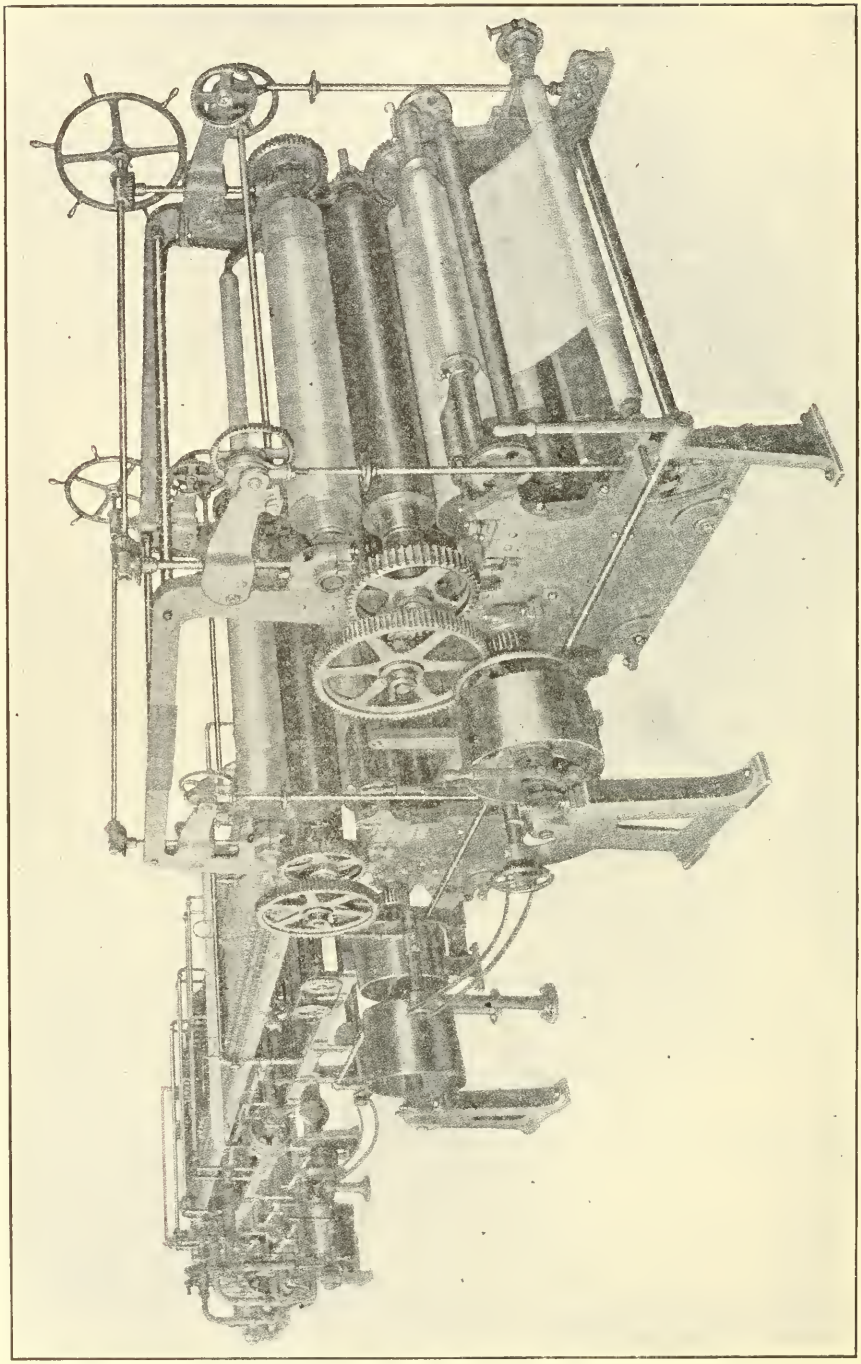


Fig. 239.—Mercerising Range for Cloth with Two Impregnators, Stenter and Washers. (Haubold System.)

and put through the spinning processes. The result, however, is that owing to the strong twist required to prevent shrinkage, only the outer layer of fibers are mercerised. Bourcart [1] also attempts the mercerisation of loose cotton in a somewhat similar manner by holding the fiber in a stretched condition between endless metal fabrics. Mather, Hübner and Pope [2] have also constructed a somewhat similar machine, only the caustic soda lye is injected through the fiber held firmly between two sheets of perforated metal. Kleinewefer's Söhne [3] constructed a centrifugal mercerising machine for loose cotton, relying on the centrifugal force to keep the fibers in a sufficient state of tension, but without any marked success. Heberlein and Co.[4] used a similar apparatus of somewhat different construction. Ahnert [5] places the well wet-out cotton in a perforated holder, puts on a high pressure and attempts mercerisation in that form, relying on the immobility of the fiber to prevent shrinkage. Machines have also been constructed to mercerise yarn on caps and delicate fabrics and wares which cannot be tightly stretched. None of these methods, however, have been successful.

In British patents 175,741 and 175,761, recently issued to A. Nelson, a machine for mercerising cotton rovings is described. The roving must

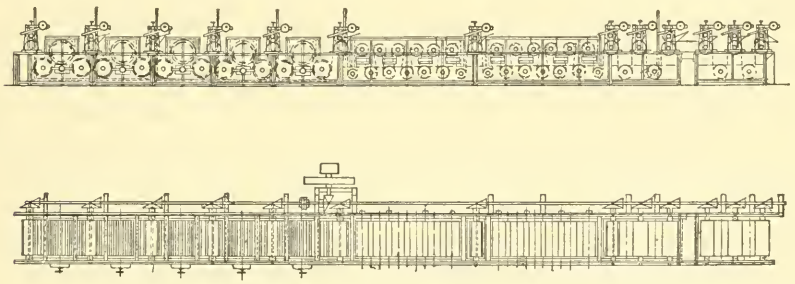


Fig. 240.—Nelson Machine for Mercerising Cotton Roving.

be especially prepared and twisted sufficiently to enable it to stand the tension. The general structure of the apparatus may be seen from the accompanying drawing (Fig. 240) which shows a side elevation and plan. The method of operating is very similar to the common form of warp mercerising machine so largely used in America. The rovings are passed through the various processes of boiling-out, mercerising, washing, drying and sizing in the form of continuous chains or ropes. Owing to the naturally loose structure of cotton rovings it seems difficult to understand how sufficient tension can be placed on the fiber so as to give it the proper

[1] *Ger. Pat.* 145,582; see *Zeit. Farb. Ind.*, 1904, p. 48.
[2] *Ger. Pat.* 177,166.
[3] *Ger. Pat.* 181,927.
[4] *Ger. Pat.* 204,512.
[5] *Ger. Pat.* 209,428.

condition for good mercerisation, and it is doubtful if cotton rovings mercerised by this method will yield a product with any high degree of luster. Also from the fact that when cotton in this rather loose condition is treated with strong solutions of caustic soda the mass of fibers become pulpy and somewhat mucilaginous in character, it is difficult to understand how the rope of roving can be maintained in its proper form. Unless the finished product is delivered from the machine in a form suitable for subsequent processing of drawing and spinning, it cannot be seen what advantage is gained by the process. It is very likely that after mercerising in this manner the cotton rovings would have to be carded up again and reprocessed before the fiber would be in a fit condition for spinning. There have been other forms of machines proposed for mercerising cotton rovings, usually depending on a carrying mechanism of slats or grids to keep the rovings in a fixed position while being treated with the various liquors. As far as mercerising in the sense of producing a fiber with a high degree of luster is concerned, none of these methods have ever amounted to much in practice, and the present method does not seem to offer any better hope in this connection. If mercerisation is only desired for the purpose of increasing the dyeing quality of the fiber without any reference to the luster, then it might be possible that some of these machines for processing rovings might serve the purpose required.

Another process for the mercerising of loose cotton is that of Lohman. The cotton, previously packed so closely that it cannot shrink, is treated with caustic lye, which is forced through it by atmospheric pressure, a vacuum having been first made in the receptacle in which the cotton is packed. In another method the cotton is packed tightly between two wire gauze fabrics, in which state it is carried through the mercerising lye and the rinsing process. Mercerising in a centrifugal machine has also been adopted, the centrifugal force being relied upon to stretch the fiber sufficiently to prevent shrinkage, springs being provided, which press the cotton against the sides of the basket. This latter process has recently been improved upon according to a patent of Heberlein, in which the use of springs is avoided by waiting until the centrifugal force alone has pressed the goods tightly against the side of the basket before adding the caustic soda; this method can be applied to centrifugals with a horizontal or vertical axis. The basket should be double in the former case, and there should be two perforated drums, one inside the other. The fibers should be placed into the intermediate space and packed there as uniformly as possible. The machine must be kept in motion in either case uninterruptedly throughout the mercerisation and the subsequent rinsing processes. The speed of the centrifugal can hardly be too great, so far as the action on the goods is concerned.

This method, it is claimed, has the great advantage that it is appli-

cable to yarn and fabrics as well as to loose cotton, and also that it can be adapted to the treatment of other vegetable fibers, such as linen, jute, and ramie; these latter claims may, however, be disregarded. The method is worthless in itself for those fibers which lie parallel to the circumference of the centrifugal shell exactly as much as fibers mercerised in a state of rest, no matter what the centrifugal force. In addition, the fibers crossing them shrink, because they are pressed against them, whilst if the goods are packed in a thin layer felting, an undesirable result is sure to occur. If the goods are thickly packed, it is scarcely possible for the centrifugal force alone to secure sufficient penetration, without introducing the lye under high pressure.

In order to avoid the use of this extra pressure, a method has been patented by Carl Ahnert, of Chemnitz, in which a specially prepared lye is used, which is said not only to penetrate the cotton easily, but to keep it from moving, so that mercerisation, rinsing, souring, and the second rinsing are all carried out without shifting the goods or altering the pressure. In this system, the cleaned loose cotton is first wetted out in hot water. It is then put under heavy pressure in the soaking vessel, between two perforated plates, which is sufficient to prevent all motion and shrinking during mercerisation. The cotton is packed as uniformly as possible, so that every part is subjected to the same pressure. To secure this result the cotton is placed in layers, with wire netting interposed. The materials are then submitted in turn to the action of the various liquids, the mercerising lye and wash-water being forced through them by the usual means.

Cotton cloth is principally mercerised in the unbleached condition. There has been some dispute as to which is best: to mercerise first and bleach, or to bleach first and then mercerise; experience, however, appears to favor the first method. In the bleaching operations, which usually involve a rather severe treatment of the cotton first with moderately strong alkalies, and subsequently with solutions of bleaching powder, the fiber suffers more or less chemical alteration, so that in the mercerising process it can no longer enter into proper chemical union with the caustic soda employed; and hence complete true mercerisation is not effected. Although cotton should be thoroughly scoured (" boiled out ") before being mercerised, it is best not to use alkalies for the purpose, but to employ Turkey-red oil (or other suitable sulfated oil) or soap. If bleaching is carefully conducted after mercerising, the injury to the luster of the fiber is very slight. Mercerised cotton does not require a prolonged boiling in alkalies previous to the operation of bleaching as with ordinary cotton.

To obtain the best conditions for high luster, yarn should be well " gassed " (singed) before mercerising, as otherwise the external, hairy

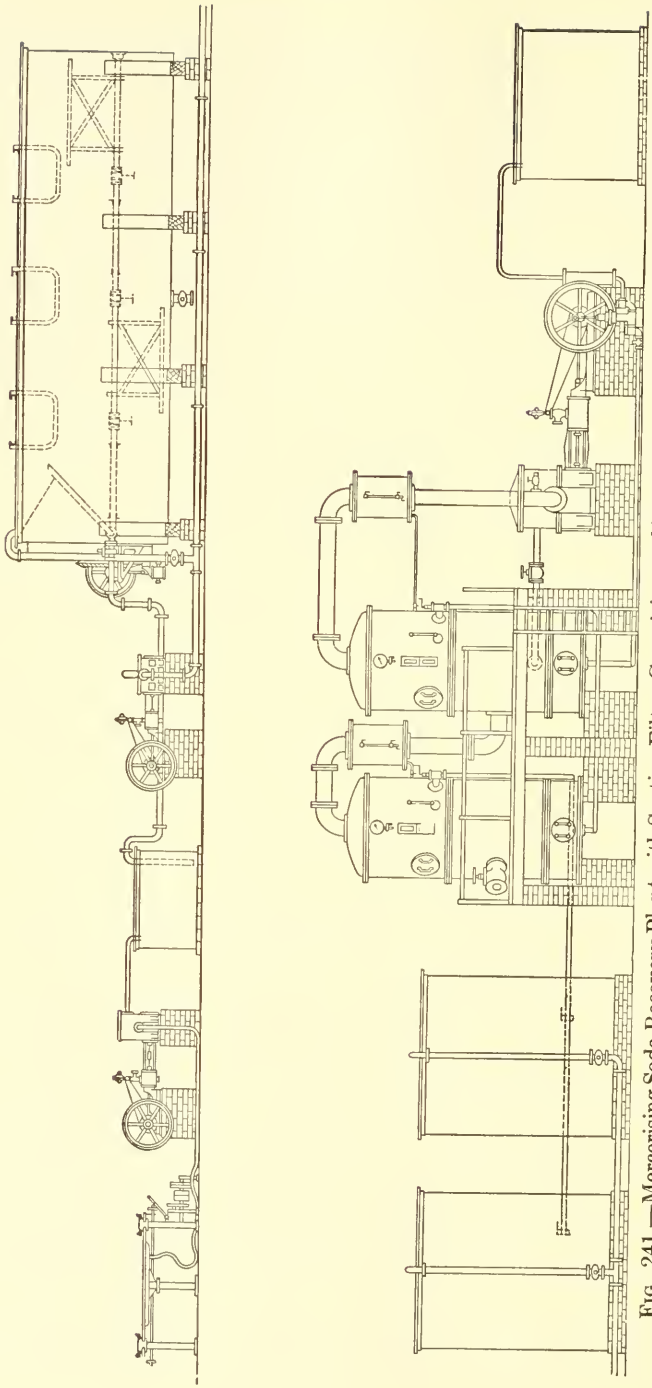


Fig. 241.—Mercerising Soda Recovery Plant with Suction Filter, Causticiser and Double Effect Evaporator. (Scott System.)

fibers remain loose and cannot be subjected to tension. As a result, these fibers shrink, and, remaining without luster themselves, hide to a certain extent the lustered surface of the yarn. Moreover, caustic soda has a felting action on these free filaments, and felting is especially detrimental to luster.

Another method of preparing or boiling-out cotton yarn or cloth for mercerising is to steep in a warm liquor containing a malt preparation, squeeze out, and allow to lay overnight. The malt preparation causes a slight fermentation in the pectin substances of the fiber which changes them to soluble compounds and thus permits of their easy removal. It also tends to soften the fiber so it is more easily penetrated by the caustic soda solution in its subsequent treatment. Some mercerisers also adopt the method of passing the yarn through a boiling dilute solution of soda ash, squeezing out excess of liquor, and then allowing to stand overnight piled up in the wet state. This condition also induces a fermentation of the pectin matters, and is said to yield a somewhat softer yarn after mercerising.

In mercerising cloth the action taking place between the sizing materials (always present to a greater or lesser degree in cotton cloth) and the caustic alkali is sufficient at times to raise the temperature considerably, which may result in a deficient luster. In such cases recourse must be had to artificial cooling by addition of ice or a current of cold water in order to prevent an undue rise in temperature.

When mercerised cotton is to be bleached, it is best, after the first rinsing, to remove the major portion of the caustic soda and arrest the mercerisation, but not to rinse again in acidulated water, as would ordinarily be done if the material were not to be immediately bleached. The small amount of caustic soda which still remains in the cotton acts in a beneficial manner in bleaching.

19. Recovery of Caustic Soda from Mercerising Liquors.—As the caustic soda taken up by the cotton in its mercerisation has to be all removed again from the material before the process is completed, it may readily be understood that a large proportion of the caustic soda must be wasted in the wash waters unless proper means be adopted for its recovery and purification. In the economical operation of the mercerising process it becomes necessary to recover efficiently the caustic soda from the waste wash waters. This requires a concentration of these wash waters, and a purification of the lye so that it may be suitable to use over again.[1]

[1] For description of methods for recovery of caustic soda in mercerising liquors, see *Zeit. Farb. Ind.*, 1910, p. 157. Also refer to O. Ventner, *Ger. Pat.* 211,566; Krais and Petzold, *Ger. Pat.* 216,622; Krais, *Brit. Pat.* 15,352 of 1907 and *Fr. Pat.* 379,992; also *Zeit. Farb. Ind.*, 1909, p. 107; Wallach, *Ger. Pat.* 202,789; Haubold, *Ger. Pat.* 205,962, and 212,900; Möller-Holtkamp, *Ger. Pat.* 207,813.

When arrangement is made for the recovery of the caustic soda it is best to use the wash waters in such a manner that when the material first emerges from the mercerising liquor, and is consequently heavily saturated with caustic soda, it is washed by water already containing some caustic soda derived from previous washing. That is to say, the mercerised goods are run in the opposite direction to the flow of the wash water through a series of tanks, so that the final washing is with fresh water. This allows of the wash water in its final use to be rather well concentrated, and consequently it can be more economically evaporated.[1] In order to recover economically the waste caustic soda from the mercerised goods it is necessary to obtain the waste liquor at as high a degree of con-

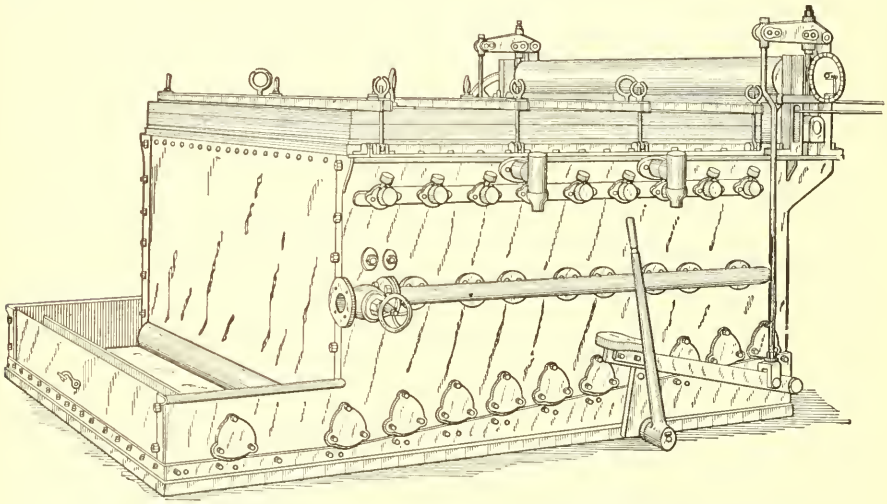


Fig. 242.—Steamer for Recovery of Caustic Soda. (Matter System.)

centration as possible. In the usual washing operation as generally employed after mercerising, the waste liquors are so dilute that it is a question as to whether it would pay to purify and evaporate them.

The wash waters become contaminated of course with more or less foreign matter and color and size from the goods, and there is also formed a good proportion of sodium carbonate by reason of the exposure of the caustic soda solution to the air. The purification and recaustification of these liquors are carried out by mixing in a tank with a suitable proportion of slaked lime and allowing the sludge to settle. The clear purified liquor is drawn off and evaporated in suitable vacuum evaporators until concentrated to the proper degree for being again available for use (about 50° Tw.).

[1] See Scott & Co., *Brit. Pat.* 19,734 of 1902.

Recently it has been found that in the mercerising of piece goods a very economical and effective method of washing is by the use of steam instead of water.[1] This removes the caustic soda from the cloth much quicker and gives a wash water of a comparatively high concentration (14°–16° Tw.), so that the cost of subsequent evaporation is low. By this method of recovery from 96–98 percent of the caustic soda may be regained.

In the Bemberg or Matter process[2] a special steaming apparatus shown in Figs. 242 and 243 is employed, also a concentrating apparatus shown in Fig. 244. The course of the material through the chamber is

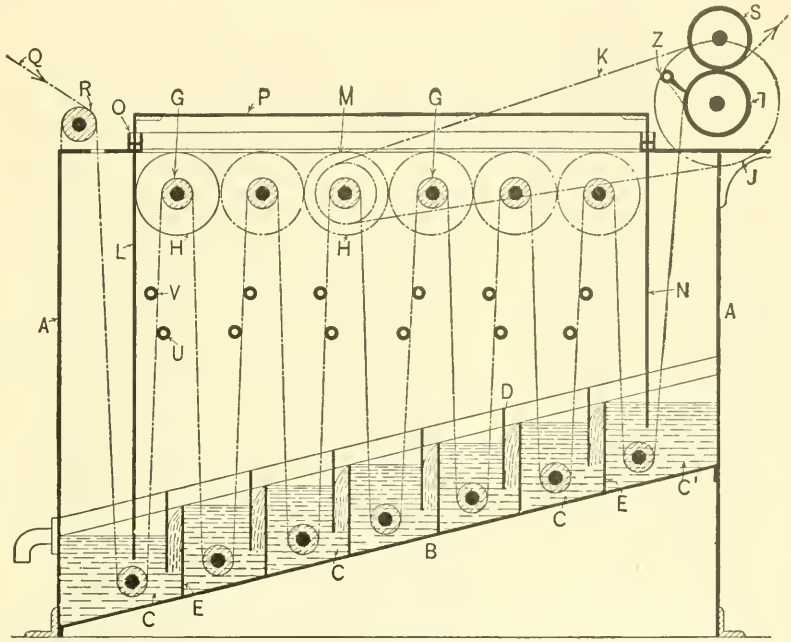


Fig. 243.—Diagram of Matter Steamer for Washing Mercerised Cloth.

shown in Fig. 243. (*A*) represents a chamber on the floor of which is arranged a vat (*B*), subdivided into a number of separate compartments (*C*) by the partitions (*D*) and (*E*) which are so arranged that a fluid is able to flow downwards from the topmost compartment (C^1) to the bottom. In the compartment (*C*) are arranged the rollers (*F*), and in the upper part of the chamber another series of rollers (*G*) is arranged, actuated by the wheels (*H*), which are in turn driven by the belt (*K*) from the pulley (*J*) to the pulley (*M*). In the chamber (*A*) vertical partitions (*L*, *N*)

[1] See Matter, *Ger. Pat.* 215,045 of 1908; also Petzold, *Brit. Pat.* 20,656 of 1911.

[2] See *Ger. Pat.* 215,045 and *Brit. Pat.* 20,656 of 1911.

are arranged, which partitions dip into the liquid in the vat (*B*), while they also carry channels (*O*) filled with liquid, into which drops a cover (*P*), so that by this hydraulic joint an airtight space is obtained inside the chamber (*A*).

The material (*Q*) coming from the mercerising machine is carried over a cylinder (*R*) into the lowest compartment (*C*), then upwards over the rollers (*G*), downwards into the next compartment (*C*), and so on in a zigzag course until the material passes out of the chamber (*A*) between

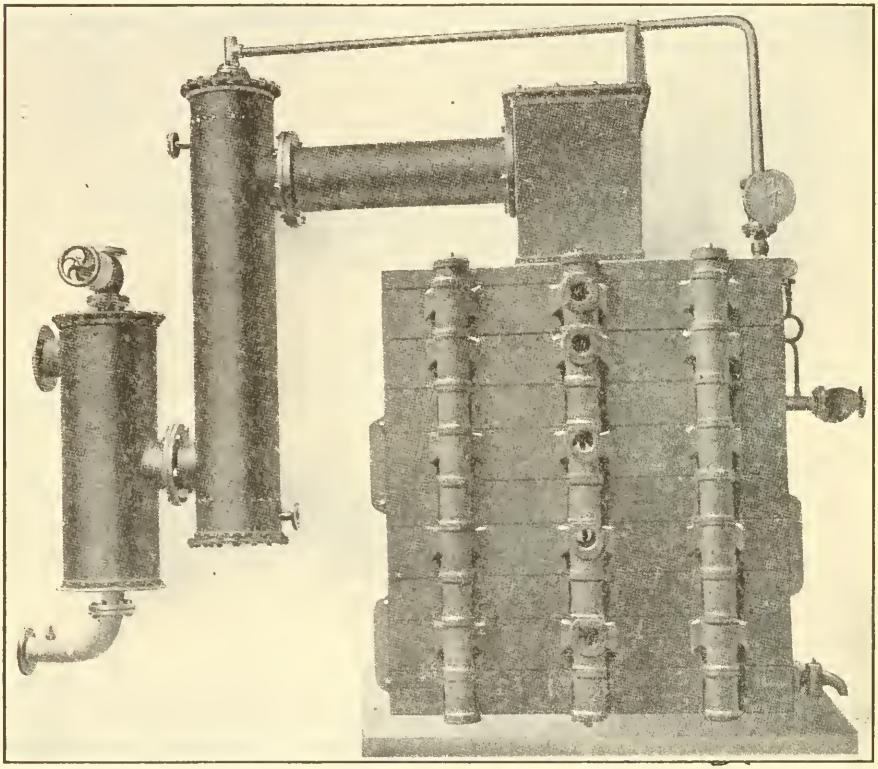


Fig. 244.—Evaporator for Matter System of Caustic Soda Recovery.

the squeezing rolls (*S*, *T*) ready to be taken where required for further treatment. The removal of the lye from the material takes place inside the airtight chamber, and for this purpose pipes (*U*) and rods (*V*) are fitted across the chamber in such a position that the material is stretched between them. The pipes (*U*) are perforated on the side towards the material, and steam is led into the pipes, passing out through the holes and acting on the material carried past in such a manner that the lye is removed from the cloth. The rod (*V*) serves to strip off the lye collected

on the surface of the material by the blast action of the pipe (U), so that it falls down into the compartments (C). The process is repeated until the material finally passes out almost free from lye, through the rolls (S and T), but before reaching the latter the material is subjected to a powerful water spray which is supplied through a pipe (Z). This water flows into the compartment (C^1), and mixes therein with the lye. This mixed liquid flows into the next lower compartment, which in turn supplies the one lower still, and so on. It will at once be seen that each succeeding lower compartment commencing from (C^1) contains stronger lye, the concentration of the series being regulated by the amount of water passing through the pipe (Z). This confers the important advan-

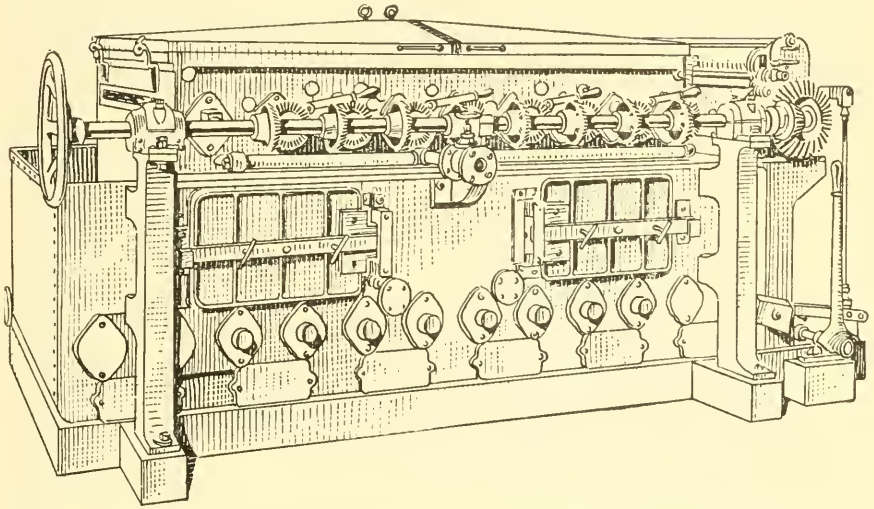


Fig. 245.—Steamer for Caustic Soda Recovery. (Krais System.)

tage that lye can be drawn off for direct use from each compartment without its having to be regenerated.

20. Properties of Mercerised Cotton.—Apart from its high luster and somewhat increased tensile strength, mercerised cotton exhibits but few apparent differences from the ordinary fiber. Toward dyestuffs and mordants it is rather more reactive and consequently will dye deeper shades with the same amount of dyestuff than ordinary cotton; this property is rather to be ascribed to the increased absorptivity of the fiber than as the result of any chemical modification of the cellulose composing it; it is also independent of the method of mercerising, that is, whether accompanied by tension or not.

Haller [1] has advanced the theory that the increased affinity of mercerised cotton for dyes is due to the removal of the cuticle from the fiber

[1] *Zeit. Farb. Ind.*, 1907, p. 125.

in mercerising, it being presumed that this cuticle or tough skin tends to resist the free transfusion of solutions of dyes and mordants into the fiber. This view, however, is opposed by Herzog, who shows that the cuticle of both the raw and mercerised cotton fiber is approximately the same in both chemical and physical properties, and concludes that the increased reactivity is caused by the hydration of the cellulose and changed physical structure of the cell-wall. Justin-Mueller [1] takes the view that mercerised cotton through the treatment with caustic soda acquires a gelatinous condition and becomes more absorptive. Dreaper considers the more highly developed colloidal nature of mercerised cotton the cause of its greater reactivity with dyestuffs.

Wichelhaus and Vieweg have studied the action between mercerised cotton and certain metallic oxides, and found it to absorb 3.82 percent of barium hydrate from a $\frac{1}{5}$ normal solution, and 2.18 percent of strontium hydrate from a $\frac{1}{10}$ normal solution.

Mercerised cotton exhibits greater chemical activity than ordinary cotton. In preparing artificial silk and other plastic cellulose materials using viscose, cuprammonium cellulose, or cellulose acetate solutions, it is nearly always the practice to start with mercerised cellulose, as this dissolves much better in the required reagents than ordinary cellulose.

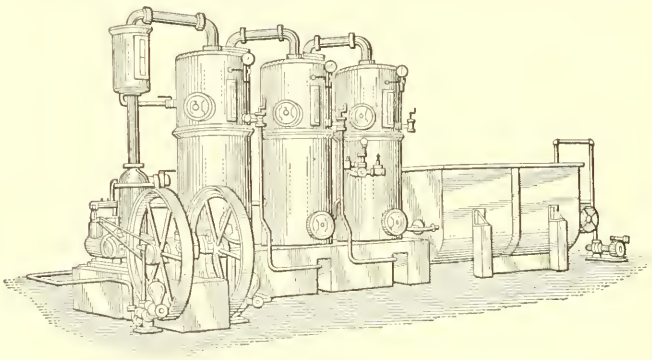


Fig. 246.—Triple Effect Evaporator for Caustic Soda Recovery. (Krais System.)

The increased affinity of mercerised cotton for substantive dyes is a very characteristic property. Mercerised cotton requires from 20 to 50 percent less coloring matter than ordinary cotton for the production of the same intensity of color.

Schaposchnikoff and Minajeff [2] have investigated quantitatively the difference in dyestuff absorption between ordinary and mercerised cotton. With indigo, substantive dyes, tannin dyes (basic), and sulfur dyes, the mercerised cotton takes up about 40 percent more; with developed dyes, however, the difference is only 4 to 10 percent. In padding with aniline

[1] *Bull. Soc. Ind. Rouen*, 1905, p. 35.

[2] *Zeit. Farb. Ind.*, 1903, p. 257; 1904, p. 163; 1905, p. 81; 1907, pp. 233, 252, 309, and 345.

salt the mercerised fiber takes up somewhat less, but in spite of this the color is darker. In the case of mordant salts contradictory results are obtained; some are absorbed better and some not so well by the mercerised cotton. In the dyeing of Turkey Red there is practically no difference to be observed between the two cottons; but on the contrary, mercerised cotton dyes more readily with the mineral colors (Manganese Brown about 12.5 percent and Iron Buff, 40 percent).

Knecht [1] has made comparative tests with various mercerised and unmercerised samples of cotton in order to determine the quantity of coloring matter fixed in each case. The dyestuff employed was Benzopurpurine 4B, and the amount of dyestuff fixed was determined by the titanous chloride method. A summary of his results are given in the following table:

Dyestuff Fixed by 100 Grams. of Cotton.	Nature of Cotton Dyed.
0.69	Ordinary cotton not boiled out.
2.78	Cotton mercerised with NaOH, 33° Bé.
5.23	" treated with HNO_3 of 43° Bé.
1.55	" boiled out, not mercerised.
2.90	" " mercerised with tension with NaOH of 29° Bé.
3.39	" " " without tension with NaOH at 29° Bé.
1.50	" bleached, not mercerised.
2.86	" " mercerised with tension at 29° Bé.
3.54	" " " without tension at 29° Bé.

The next table gives the results using Egyptian cotton under varying conditions of mercerising:

Dyestuff Fixed by 100 Grams of Cotton.	Concentration of Caustic Soda Solution.
1.77	Unmercerised cotton.
1.88	Mercerised at 10° Bé.
2.39	" 14° Bé.
2.57	" 16° Bé.
2.95	" 19° Bé.
3.02	" 21.5° Bé.
3.15	" 24° Bé.
3.27	" 26.5° Bé.
3.38	" 29° Bé.
3.50	" 31° Bé.
3.56	" 33° Bé.
3.60	" 35.5° Bé.
3.66	" 37.5° Bé.

[1] *Jour. Soc. Dycrs & Col.*, 1908, p. 68.

The last table shows that the affinity of cotton for direct dyestuffs increases in proportion to the degree of mercerisation; consequently, the degree of mercerisation may be ascertained by the quantity of Benzopurpurine fixed by 100 grams of cotton.

Hübner and Pope [1] have studied the dyeing properties of mercerised cotton as compared with ordinary cotton and have shown that the increase in the absorption of dyestuff is dependent on the degree of mercerisation. Their results are stated as follows:

(1) Cold caustic soda solution of 1° Tw. has a considerable effect in increasing the affinity of cotton for substantive dyes, and from 0° to 18° Tw. the increase in affinity for the dyestuff is roughly proportional to the concentration of the caustic soda. Though dilute solutions of caustic soda in the *cold* have the effect of increasing the dyeing power of cotton, such solutions used *hot* have no such effect. Cotton yarn boiled with caustic soda solution of 2° Tw. has the same affinity for dyestuffs as untreated cotton.

(2) Between 18° and 22° Tw. the increase in the concentration of the soda has a greater effect in increasing the affinity of the cotton for the color than corresponding increases of lower concentrations. With soda of 22° to 26° Tw. the effect becomes still greater, and from 26° to 30° Tw. the increased affinity is still much greater.

(3) Above 30° Tw., however, an increase in the strength of the caustic soda solution has less effect in increasing the affinity for dyes. Between 55° and 70° Tw. the increase in affinity is very slight.

(4) When mercerised with caustic soda solutions above 70° Tw. there is a decrease in the affinity, so that cotton mercerised with caustic soda of 80° Tw. shows the same dyeing power as that mercerised at 35° Tw.

Hübner and Pope have also studied the degree of contraction in cotton yarn caused by treatment with caustic soda solutions of different strengths. The following table shows the results of their tests:

Strength of NaOH, ° Tw.	Length of Hank, Yards.	Contraction, Percent.	Strength of NaOH, ° Tw.	Length of Hank, Yards.	Contraction, Percent.
—	200	—	20	186.8	6.6
0 (water)	198	1.0	22	171.3	14.3
1	196.4	1.7	24	163.1	18.4
2	195.7	2.1	26	160.3	19.8
3	195.6	2.2	28	160.0	20.0
4	195.5	2.2	30	158.2	20.9
5	195.2	2.4	35	150.2	24.9
6	194.2	2.9	40	143.7	28.1
7	193.7	3.1	45	141.0	29.5
8	194.2	2.9	50	154.2	28.9
9	194.0	3.0	55	142.7	28.6
10	194.2	2.9	60	145.3	27.3
12	194.5	2.7	65	149.2	25.4
14	192.7	3.6	70	150.3	24.8
16	190.4	4.8	75	152.8	23.6
18	188.7	5.6	80	154.2	22.9

[1] *Jour. Soc. Chem. Ind.*, 1909, p. 404.

It will be noticed that at about 20° Tw. there is a sudden increase in the amount of contraction, and that a maximum is reached at about 45° Tw.

Mercerised yarn has the disagreeable property that it sometimes gives streaky and uneven dyeings. The cause of this is often quite unknown, and the unevenness often disappears in the next batch as mysteriously as it came in the one before. There must, of course, be something wrong either in the mercerisation or in the dyeing. Dyers who mercerise their own yarn are best able to investigate the matter, but many dyers are called upon to dye yarns mercerised by others. When uneven dyeing manifests itself, the only possible course is to dye with the same yarns a small batch of other yarn known to be perfectly and uniformly mercerised, and a stock of such yarn should always be at hand. If, in the same bath, all the yarns dye badly, the fault is in the dyeing; or in both dyeing and mercerising, if the perfectly mercerised yarn, although defective, is much better than the yarn of unknown character. It is very difficult to rectify unequally mercerised yarn. A second mercerisation is worse than useless, for then those parts which were over-mercerised in the first operation become still more over-mercerised, for they have more affinity for the caustic lye than the parts less mercerised at first. Bleaching is utterly useless, unless the uneven mercerisation is detected before dyeing. In this case a soaking in weak, warm methylated spirit, followed by an ordinary permanganate bleach, will be effective in many cases.

It has also been found that the uneven dyeing of mercerised yarns may often be prevented by treating the mercerised cotton before dyeing with a solution of caustic soda of about 25° Tw. and then washing thoroughly. The fact that mercerised yarns from different mercerising plants will nearly always dye somewhat differently is well known. In many cases it is not possible to run the mercerised cotton of one mill along with that of another if the fabric so made is to be dyed. This difference in coloring is probably due to the fact that one merceriser may give the yarn a much longer treatment in the caustic soda bath than the other. It may also be caused by the use of different qualities of water in the mercerising process, or in the use of different methods of washing and softening.

21. Tests for Mercerised Cotton.—With a solution of iodine in potassium iodide mercerised cotton exhibits a reaction which serves to distinguish it from ordinary cotton. By immersing samples of ordinary and mercerised cotton for a few seconds in a solution of 20 grams of iodine in 100 cc. of a saturated solution of potassium iodide, then washing with water, the ordinary cotton becomes pale brown while the mercerised cotton remains black. On continuing the washing the ordinary cotton finally becomes colorless, while the mercerised sample remains a bluish black, which fades only very slowly.

On treatment of cotton with a 1/100 normal solution of iodine, and exposing the sample to the air, ordinary cotton becomes nearly decolorised in a very short time, while mercerised cotton will exhibit a gradation of color corresponding to the strength of caustic soda used in mercerising. It also appears that cotton mercerised without tension has a greater absorptive power for iodine than cotton stretched during the mercerisation.

Another reagent for mercerised cotton is a solution of 46 grams of aluminium chloride in 100 cc. of water to which is added 15 to 20 drops of iodine solution. On steeping mercerised cotton in this solution for one hour it gives a dark chocolate-brown color, while ordinary cotton remains colorless.[1]

By using a solution containing 280 grams of zinc chloride in 300 cc. of water, to 100 cc. of which are added 20 drops of a solution of 1 gram of iodine and 20 grams of potassium iodide in 100 cc. of water, more distinctive colorations between ordinary and mercerised cotton can be obtained than is the case even with the above described solution of iodine.[2] The color given by this reagent on ordinary cotton is more readily removed, while the color left on the mercerised cotton is more persistent. By use of this solution the strength of caustic soda solution employed in the mercerisation of a sample may be determined.

Hübner (*Jour Chem. Soc.*, 1908, p. 105) gives a table of tests showing the reaction of this reagent on cotton samples, mercerised with different strengths of caustic soda:

Strength of Caustic Soda, ° Tw.	I. 20 Drops of Iodine Solution.	II. 10 Drops of Iodine Solution.	III. 5 Drops of Iodine Solution.
0	Slight red tint	Remains white	Colorless
10	Faint red	Very faint brown	"
20	Dark chocolate	Darker brown	"
23	Darker, bluer	Darker, bluer	"
26	Much darker and bluer	Much darker and bluer	"
30	Very dark navy blue	Darker, reddish blue	Faint blue
40	Black	Much darker	Bluer
50	Black	Darker than 40	Darker blue
60	Black	Darker than 40	Slightly lighter
70	Black	Darker than 40	Lighter

[1] Hübner, *Jour. Soc. Chem. Ind.*, 1908, p. 110.

[2] See Lange (*Färb. Zeit.*, 1903, p. 369). The sample should be left in the reagent for three minutes and then washed; the color is quickly removed from ordinary cotton, while the mercerised cotton remains blue for some time.

The different proportions of the iodine solution were added to 100 cc. of the zinc chloride solution. When woven fabrics are examined, the sample should be first dipped in water and pressed between filter paper before applying the reagent. Preliminary removal of dyestuffs does not interfere with the test.

Another characteristic test for mercerised cotton is its behavior with Benzopurpurine.[1] If ordinary cotton and mercerised cotton be dyed with Benzopurpurine in a dilute dyebath, then hydrochloric acid added drop by drop until the ordinary cotton is just changed to a blue color, the mercerised cotton will still remain a bright red.[2] This test was first proposed by Knecht, who conducted it so that sufficient hydrochloric acid was added to change both samples to a blue color. Then a solution of titanous chloride was added cautiously to the liquid until just before decolorisation when the sample of ordinary cotton remained blue while that of the mercerised cotton became red.[3]

Knaggs [4] conducts the same test by using a very dilute solution of Benzopurpurine 4B, 5 cc. of the dye solution (0.1 gram per liter) to 100 cc. of water being employed and acidifying the boiling liquid with adding titanous chloride. Cotton will be colored blue-black while mercerised cotton will dye red.

David [5] tests the difference between mercerised and non-mercerised cotton as follows: The yarn or fabric is boiled-out and as much of its color removed as possible; it is then spotted in a stretched condition with caustic soda liquor of 40° Bé., and further with the same liquor diluted with water 1 : 1 and 1 : 3. The sample thus prepared is then dyed with Congo Red; if the cotton was previously non-mercerised the spotted places will dye up darker, but if the sample had been mercerised the color will be uniform all over.

Higgins [6] has shown that mercerised cotton is more hygroscopic than ordinary cotton, and, furthermore, the proportion of moisture absorbed increases with the " degree of mercerisation," as shown by the following table:

[1] In carrying out this test care must be had to use only pure Benzopurpurine, as the presence of Safranine or other compounds usually present in commercial samples of Benzopurpurine may vitiate the delicacy of the test.

[2] Knaggs, *Jour. Soc. Dyers & Col.*, 1908, p. 112. The fact that the mercerised cotton remains red is evidently not due to any residual alkali in the fiber, for if sufficient acid is added to turn the color of the mercerised sample to a blue, and this sample is immersed again in the dye solution, the red color reappears.

[3] See *Jour. Soc. Dyers & Col.*, 1908, p. 67.

[4] *Jour. Soc. Dyers & Col.*, 1908, p. 112.

[5] *Rev. Gen. Mat. Col.*, 1907, p. 261.

[6] *Jour. Soc. Chem. Ind.*, 1909, p. 188.

Degree of Mercerisation.	Moisture, Percent.
Ordinary cotton	6.20
Mercerised with caustic soda 10° Tw	6.37
" " 20° Tw	6.68
" " 30° Tw	8.40
" " 40° Tw	9.41
" " 50° Tw	9.43
" " 60° Tw	9.57
" " 70° Tw	9.69

In these tests cotton yarn was well boiled out and mercerised without tension with caustic soda solutions of different strengths. The samples were then washed, soured, washed, dried at 60° C., and then exposed to the air for some time. The moisture was determined by weighing before and after drying for eight hours at 100° C.

If these results are compared it will be noticed that a sharp increase is evident between cotton mercerised at 20° Tw. and 30° Tw., while beyond 40° Tw. the moisture becomes practically constant.

Oxley [1] states that mercerised cotton does not dye to as full a shade after drying as when dyed after mercerising but before drying. It has also been found that ordinary cotton behaves in the same manner. It is also known that cotton cloth which has been thoroughly dried, even after a long exposure to the atmosphere, will not absorb the amount of moisture it originally contained in the air-dry state.[2]

David gives a method for distinguishing mercerised cotton, based on the fact that cotton if mercerised a second time acquires no increased affinity for the dyestuff. The cloth to be treated, if colored, is first stripped of the color by treatment in hydrochloric acid, and stretched on a frame. Three solutions of caustic soda are then prepared: (1) Standing 40° Bé.; (2) 40° Bé. diluted with an equal quantity of water; (3) 40° Bé. diluted with three times the quantity of water. These three solutions are dropped on different parts of the cloth on the frame. After a short time the frame and cloth are rinsed in water to remove the caustic, then scoured with sulfuric acid, and again rinsed. The cloth is then colored with Congo Red. If the cotton before treatment was unmercerised, the spots on which the caustic solutions were dropped are of a more intense color than the other parts of the piece, while mercerised cotton shows no difference in color.

22. Ultramicroscopic Appearance of Mercerised Cotton.—Microscopic examination in polarised light affords a means of distinguishing between

[1] *Jour. Soc. Dyers & Col.*, 1906.

[2] Higgins, *Jour. Soc. Chem. Ind.*, 1909, p. 188.

mercerised and unmercerised cotton fibers. The corrugated strain lines showing strong illumination are distinctly seen in unmercerised cotton, are diffused in cotton mercerised without tension and entirely missing in cotton mercerised with tension. From ultramicroscopic investigations on mercerised cotton fibers Harrison [1] comes to the conclusion that the swelling of cotton by treatment with caustic soda solution is analogous to the swelling of gelatine by water, and is caused not by a chemical action on the cellulose molecule itself, but by a dispersion of a colloidal complex of cellulose representing the fiber. The degree of dispersion is greater when mercerised without tension than with tension. Mercerised cotton, therefore, is nothing more than ordinary cotton with its cellulose complex in a more highly dispersed condition.

23. Cellulose Hydrate; Hydracellulose.—As previously mentioned mercerised cotton is considered to be an alteration product of cellulose known as cellulose hydrate or hydracellulose. The cellulose is supposed to have united with a molecule of water giving $C_2H_{10}O_5 \cdot H_2O$. Hydracellulose is not to be confused with hydrocellulose, as in the latter a distinct rearrangement in the molecule takes place, the cellulose being hydrolysed. The form of combination of the water in the case of hydracellulose, on the other hand, is probably similar to that in various crystalline salts, containing water of hydration (or crystallisation). The researches of Ost and Westhoff [2] on " cellulose hydrates " (including mercerised cotton) indicate that when these substances are freed from all traces of hygroscopic moisture they have the same composition as ordinary cellulose, i.e., $C_6H_{10}O_5$. Hydrocelluloses, on the other hand, appear to contain chemically combined water.

Hydracellulose has the property of absorbing a greater proportion of alkali from dilute caustic soda solutions than non-hydrated cotton, as shown by the following table, using a 2 percent solution of caustic soda:

Character of Cotton.	NaOH Absorbed,
Ordinary purified cotton	1
Cotton mercerised in 8 percent NaOH	1.4
" " " 16 percent NaOH	2.8
Hydracellulose of viscose silk	4.5
" " cuprate silk	4.0

The amount of alkali absorbed by hydracellulose does not increase beyond 2.8 percent even if the concentration of the mercerising bath is above 16 percent NaOH. It also seems to be independent of the temperature of the solution.

Attention may also be called to the manner in which different hydracelluloses behave with caustic soda solutions of high concentration. It

[1] *Jour. Soc. Dyers & Col.*, 1915, p. 200.
[2] *Chem. Zeit.*, 1909, p. 197.

is known that the viscose and cuprate artificial silks belong to the same general class of hydracelluloses as mercerised cotton. In fact, they are scarcely to be distinguished in their reducing properties. Between these artificial silks, however, and mercerised cotton, there apparently exists a marked contrast as to the degree of hydration. The former when treated with strong caustic soda solutions and washed with water, become gelatinous and almost completely dissolve. Mercerised cotton, on the other hand, remains insoluble. The artificial silks consist of cellulose regenerated from solutions, and perhaps consist of cellulose molecules which have not suffered much condensation, whereas mercerised cotton may consist of highly condensed polymers of the simple cellulose molecule, hence its dissociation is much more difficult.

It may, therefore, be concluded that there exist various degrees of hydration of cotton, and these may be determined by the proportion of caustic soda absorbed. That is to say, the degree of hydration may be measured by the quantity of alkali (NaOH) absorbed by 100 grams of cotton when treated with a 2 percent solution of caustic soda. The following table shows this degree of hydration:

Concentration of Mercerising Liquor, Percent NaOH.	NaOH Absorbed per 100 Grams of Cotton.
Unmercerised	1
4	1
8	1.4
12	1.8
16	2.8
20	2.8
24	2.8

The practical determination of the degree of hydration of mercerised cotton may be made according to the following method: There is placed in a flask 200 cc. of a 2 percent solution of caustic soda; 50 cc. of this solution is titrated with N/2 sulfuric acid. In the remaining solution there is placed 3 grams of air-dried cotton. After agitating for thirty minutes, 50 cc. of the solution is again titrated with N 2 sulfuric acid. The difference in the titrations will indicate the amount of alkali absorbed by the cotton.

Hydracellulose may also be formed by the action of concentrated acids under proper conditions. This accounts for the mercerising effect of such acids. The same is also true of the action of the double iodide of barium and mercury and of solutions of zinc chloride on cotton; hydracellulose is produced in each case, and a mercerising effect is obtained.

When cotton is treated with a solution of sulfuric acid of 51° Bé., washed, and dried, the product may be dissolved in a moderately concentrated solution of caustic soda (like viscose or cuprate silks). When hydrated cotton is triturated with a solution of caustic soda sufficiently concentrated to produce mercerisation, there is obtained a viscous liquid which may be likened to a colloidal solution. This solution may be passed through a filter-press, and in this manner there is finally obtained a homogeneous viscous liquid that can be flocculated by the addition of an acid. The precipitate of regenerated cellulose may be separated by ordinary filtration.

Schwalbe [1] has determined the "copper numbers" of cotton treated with caustic soda solutions of various strengths, as follows:

	Copper Equivalent.	
	Before Hydrolysis.	After.
Untreated cotton.....	1.1	3.3
Treated with 8 percent caustic soda.....	1.0	3.2
" " 16 " "	1.3	5.0
" " 24 " "	1.2	6.0
" " 40 " "	1.9	6.5

The copper equivalent was determined in the usual manner by treatment of the material with Fehling's solution.

24. Microscopy of Mercerised Cotton.—Microscopically the mercerised cotton fiber exhibits a considerable difference from that of ordinary cotton. Whereas the latter, when viewed under the microscope, appears as a twisted flat band with thickened edges, and in cross-section like a collapsed tube, mercerised cotton appears as a rather smooth cylindrical fiber, the cross-section of which is more or less circular. It rarely happens that a fiber absolutely loses all of its twist, though the degree of mercerisation may be measured by the freedom of the fiber from irregularities and twists. Under ordinary conditions when the cotton is mercerised in a state of tension, it will also be found that many fibers will remain in their original form, or unmercerised, whereas others will be mercerised only in portions of their length. The microscopical examination of mercerised cotton is important in determining just how perfectly the process has been carried out, which may be judged by the relative number of unmercerised or partially mercerised fibers which may be present.

Hanausek [2] gives the following description of the microscopy of mer-

[1] *Zeit. angew. Chem.*, 1908, p. 1321.

[2] *Microscopy of Technical Products*, p. 66.

cerised cotton: The fibers are broad, straight, round, and smooth, with a lumen which is either visible the entire length, although narrow and varying in breadth, or only occasionally visible so that the fiber shows a row of streaks, or it may be quite invisible. Humps and depressions, corresponding to folds and twists of the original fiber, are frequently present. The fibers without evident lumen, closely resemble silk fibers, but treatment with cuprammonia brings out the lumen, and at the same time, certain marked differences between untreated and mercerised fibers. The latter swell uniformly in the reagent, without marked constrictions and the lumen does not become folded or coiled, since the fiber does not contract in length. The uniform swelling is explained by the absence of the cuticle; only in rare cases, where the fiber has obviously escaped the action of the mercerising liquid, is the cuticle present. Sometimes the inner tube is alternately enlarged and contracted, presenting in surface view the appearance of a series of rhomboids. In cross-section the fibers are nearly circular, with groups of minute granules as contents.

25. Lustering by Calender Finish.—A silky luster resembling that produced by mercerisation can be given to cotton cloth by means of what is known as a calender or Schreiner finish.[1] This is accomplished by passing the cloth between rollers under heavy pressure, one of the rollers being engraved with obliquely set lines ruled from 125 to 600 to the inch. The effect is to produce a great number of parallel, flat surfaces on the cloth, which causes it to acquire a high luster. By conducting the operation with hot rollers quite a permanent finish can be produced which closely approximates mercerised cotton. Cloth so finished, however, loses its luster in a large degree on washing. The method is chiefly known as the "Schreiner process," or in England as the "Hall" finish or "Williams" finish.[2]

Various methods have been devised to make this method of lustering of a permanent character and with more or less success, such as treatment of the calender goods with steam under pressure[3] or by finishing the cloth with a fine layer of size which is insoluble in water.[4]

[1] See H. Fischer, *Zeit. Farb. Ind.*, 1907, p. 271. Also see Deisler, *Ger. Pat.* 85,368 (Schreiner patent); Appleby, *Brit. Pat.* 170 of 1860; and Kirkham, *Brit. Pat.* 4593 of 1885 and 10,825 of 1899; Hübner and Pope, *Ger. Pat.* 167,930; Keller-Dorian, *Ger. Pat.* 185,835; Eck u. Söhne, *Ger. Pat.* 197,589; Hall, *Ger. Pat.* 177,241.

[2] See also Gardner, *Merzerisation und Appretur*, p. 150.

[3] See Sharp, *Brit. Pat.* 16,746 of 1897.

[4] See Bradford Dyers' Association, *Ger. Pat.* 212,696 and 212,695 on the use of cellulose nitrate solutions; this, however, is expensive and leaves an objectionable odor. Müller, *Ger. Pat.* 222,777, uses celluloid dissolved in dichlorhydrin; this is also too expensive. Düring, *Ger. Pat.* 206,901 and 217,679 uses albumen and casein solutions which are coagulated by steaming. Eck u. Söhne, *Ger. Pat.* 232,568, use an acid gelatine solution and coagulate by neutralising; this method, however, is expensive. Bernhard, *Ger. Pat.* 233,514, uses a dilute solution of rubber, wax or paraffin in benzene, which is also an expensive method.

The present day so-called permanent luster finish (also known as the Radium or Adler finish) is obtained by first finishing the cloth on the engraved calender for silk luster and then fixing on another calender at high temperature [1] and under great pressure (up to 300,000 lbs.). The higher the temperature the higher the luster (generally 200–300° C.).

In the Rumpf process [2] the goods (cotton piece-goods, cotton plush, velvet, and the like) are first submitted to a preliminary treatment.

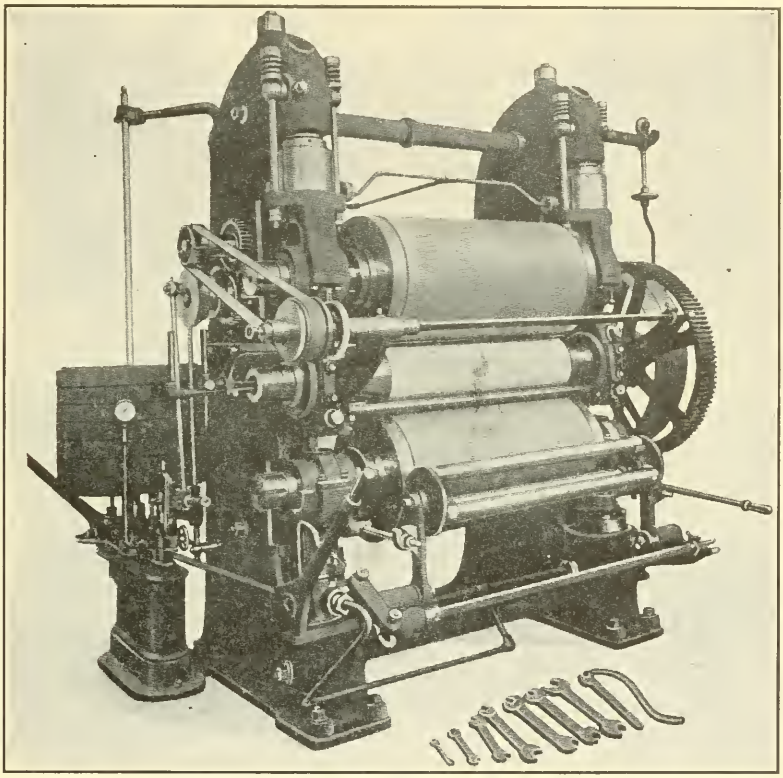


Fig. 247.—Calender for Schreiner Finish.

This consists in the goods being strongly moistened and a high shiny gloss then imparted to them by means of hot calendering or pressing, or by lustering. The shiny gloss so produced is then for the most part fixed by submitting the goods, preferably in a stretched condition, to heat of a high temperature by passing them for a long time through a very hot calender, or by passing them through gas flames, or more frequently by passing them over a strongly heated drum, or rolling them up thereon. If, in producing the gloss by the calender process, temperatures of 400° C.

[1] See Aderholt, *Ger. Pat.* 235,701.

[2] *Ger. Pat.* 220,349.

and over are used, it is possible with even one or two passages to obtain a sufficient fixation with one treatment. By the action of the heat a part of the gloss produced is lost owing to the displacement of the fibers, and cannot therefore be fixed by the heat. In order to remedy this defect the goods are previously treated by any shiny adhesive material, preferably containing starch. The goods are then drawn off—that is, treated with water, soap solution, moist steam, or other solution, and if starch has been employed, with malt or malt extract, whereby, as is known, the fatty gloss disappears and a clean and equable silky gloss remains, which

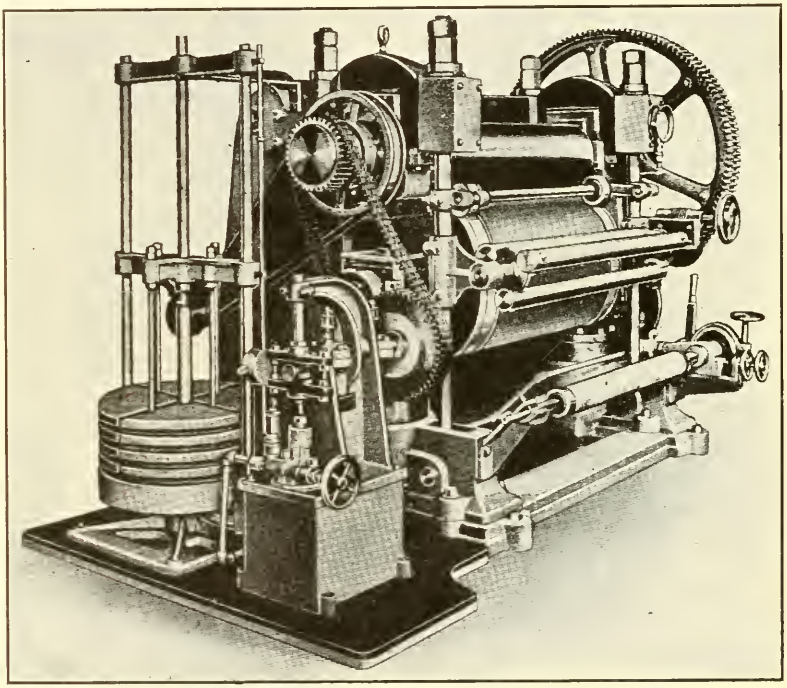


Fig. 248.—Hydraulic Schreiner Calender.

is then water and soap proof. The amount of gloss obtained depends primarily upon the amount of gloss imparted in the preliminary treatment to the goods. The degree of fixing, however, depends principally upon the temperature to which the action—that is, the fixation—of the gloss is proportionate. The heating is therefore carried as far as possible without damaging the goods.

In the Palmer process[1] the materials are passed while quite wet through strongly heated rollers with such a speed (30 to 40 meters per minute) that in spite of the great pressure and the high temperature they

[1] *Brit. Pat.* 20,645 of 1909.

emerge still wet. The water acts in this case as a protective means, in that it limits the effect of the heat upon the surfaces, and protects the center of the material against destruction by the penetration of the heat, so that a superficial luster is formed only at the areas of contact of the material with the rollers. At the same time the steam evolved from the material upon pressing removes in one operation the base and unperma-

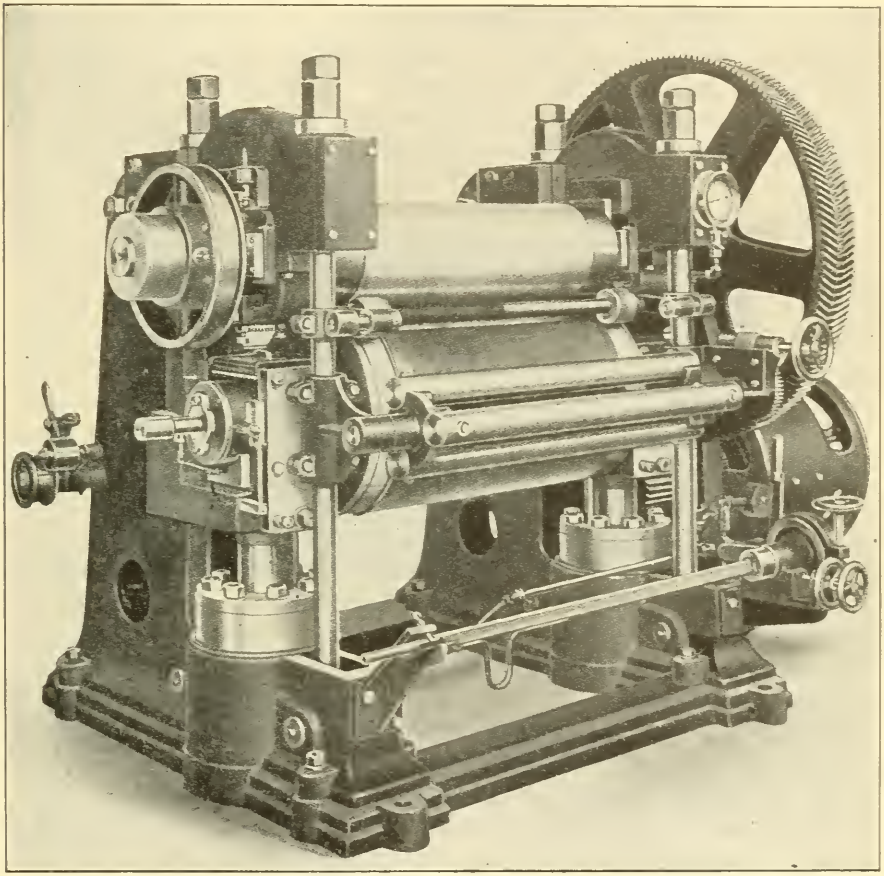


FIG. 249.—Improved Type Hydraulic Schreiner Calender. (Text. Fin. Mchy. Co.)

nent part of the luster, without any special subsequent damping being first required. In order to provide the material with permanent luster on both sides, it is passed through two calendering machines in series one after the other; the steel roller of one calender lies beneath, and that of the other on top. In order to raise the flattened shape, the yarns can, if desired, be subsequently soaked in hot water. Instead of employing simple pressure, the latter may be combined with friction—e.g., by dif-

ferent speeds of the two rollers, placing them obliquely, and so on. In a similar way to yarns, other products consisting of vegetable threads can also be treated, such as woven goods, fabrics, etc., for which as a rule treatment on one side is sufficient. Any kind of roller (polished, engraved, etc.) may be employed as the pressure roller. This process can be employed upon both mercerised and non-mercerised fabrics.[1]

Hamberg and Poznanski have described a combination of mercerisation and goffering to obtain patterns in relief that will withstand washing. The fabric is passed between two calender rollers, one of which bears the pattern in relief, the other in intaglio. If the two rollers are in register, the pattern will be printed without distortion, and, at the same time, both warp and weft threads will be stretched in the pattern. If the fabric is then treated with caustic-soda lye by passing it over a roller turning in

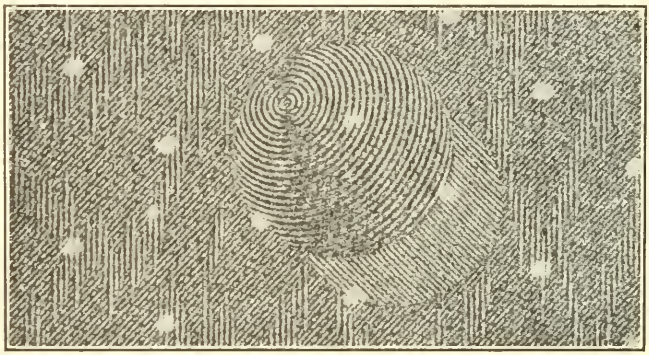


Fig. 250.—Gauffer Finish on Cotton Cloth.

the lye, but with the unprinted side in contact with that roller, the contraction of the wrong side will make the pattern permanent; the lye answers best in this particular manner of use if thickened with dextrin. The goods are then ironed and prepared in the usual manner; these patterns are claimed to be fast to washing with boiling water (Fig. 250). If the raised parts of the pattern are treated with a reserve to protect them from mercerising lye, a similar effect is obtained. Another method is to paint the raised parts of one roller with a thickened lye, so that in contrast

[1] A rather peculiar process of lustering is that of impregnating the goods, either in the dry or wet condition, with a crystallisable salt solution, such as sodium chloride or chloride of ammonium, after which the goods are passed repeatedly through a calender heated to about 100° to 200° C. The surface gloss from the steam is then obliterated from the goods in an ordinary manner, and the appearance of the goods may be rendered more refined by working it through fluted rollers. After this there remains a silk-like gloss due to minute crushed crystals intimately distributed over all the fibers throughout the fabric. It is claimed that the goods thus treated can be placed in water for days without materially losing the gloss.

to the last method, it is the pattern that contracts instead of the ground. Dyeing effects can be obtained with fabrics so treated, according to the parts that have been mercerised, and according to the degree of ornamentation. For example, light patterns on a dark ground may be readily obtained, or *vice versa*. White raised effects can be made on a colored ground by adding dyes to the mercerising lye, and interesting and valuable effects can also be obtained by raising the patterns in relief on the gig so that the raised parts show up strongly on the unraised and flat-looking ground portions of the design.

Another method of goffer lustering is described by Oliver[1] as follows: To a mixture of 455 grams sandarac gum and 910 grams castor oil, 113 grams of fine celluloid waste and amyl acetate reduced to a paste are added and finally 2.5 liters of methyl alcohol to give a syrupy consistency. The fabric is sprinkled with this composition and passed into the goffering rollers and then dried.

26. Other Methods of Lustering Cotton.—Another important finishing method for cotton whereby the character of the surface is changed by mechanical means to give it the quality of chamois or moleskin is known as the "Duvetyn" finish. This finish is produced on cotton fabrics by "emerising." It has enjoyed a run of popularity, and is still in favor. At the time of its introduction it was worked as a secret process, different finishers employing methods differing perhaps in some detail or another. Experience with the work has brought improvements, and one of these forms the subject of an invention by the Société Durbar-Delespaul, of Roubaix.[2] It is an application of the well-known process of raising or "emerising," and it is stated by the inventors that the patent involves no improvement in the technique of that process. The "emerising" process is used generally on cotton goods woven in such a way that the weft floats on the face of the cloth and the warp on the back, much the same as a moleskin. This process of finishing does not require any special treatment in the weaving, and is equally as well adapted for worsted or carded woolen fabrics as for cotton. The fabrics are emerised either in the gray or after dyeing or printing. The process changes the surface of the cloth—gives it the appearance of velveteen, chamois, or the skin of the mole. The operation is very simple, and consists of subjecting the cloth in two or three passages to the action of several rollers which revolve rapidly in a direction opposite to that in which the cloth is moving. These rollers are covered with emery cloth.

Pulverised flint, stone, glass or sand may be substituted for the emery. The action of the roller on the weft of the cloth produces a very short, thick nap, with the fibers standing straight from the surface of the cloth. The extent of this action depends, of course, on the nature of the fabric

[1] *Fr. Pat.* 508,241. [2] *Fr. Pat.* 449,266.

to be finished, and is regulated by the tension of the cloth, the speed and number of the rollers, and on the fineness of the emery with which the rollers are covered. It is evident that carded woolen goods can be finished by this process more easily than worsteds, owing to the difference in the twist of the yarn. Emerising differs radically from napping or raising on the ordinary raising machine: the latter tears the fibers from the thread in order to form the nap. Emerising consists not in tearing the fibers out, but in wearing or polishing the surface. Both raising and emerising, however, serve the purpose of reducing the strength and solidity of the fabric. In order that the nap may be uniform it is necessary that the fabric should possess a certain degree of stiffness. For this reason the cloth is heavily sized, and this prevents the action of the emery penetrating deeply into the fibers. The ordinary glue used in finishing answers the purpose, and after it has been applied the material is dried thoroughly before emerising. By covering the rollers with bands of emery the Duvetyn finish can be produced in the form of stripes.

27. Crêpe Effects by Mercerising.—Crêpe effects may be produced on all-cotton goods by employing mercerised cotton yarns for the warp, suitably protecting these with gum, and then using plain cotton yarns for the filling, and finally mercerising the woven fabric. The filling yarns will contract and thus give a crinkled or crêped fabric.

Crêpe effects on cotton-wool fabrics may also be produced by the process of mercerisation. If the cotton is used in the fabrics in either stripes of pattern effect it may be shrunk suitably by treating the fabric with strong solutions of caustic soda without tension. If a caustic soda solution of 50° Tw. is used at a temperature below 10° C. and for one to three minutes, the cotton will be properly shrunk without affecting the strength or quality of the wool, the latter fiber only becoming somewhat lustered and hardened.

The usual method of crêping cotton fabrics, however, is to employ the mercerising reaction in connection with printing. By printing on a strongly caustic paste in stripes or any other pattern effect, that portion of the cotton fabric subjected to the action of the caustic soda will contract considerably, leaving the rest of the fabric in its natural condition. In this manner seersucker and crinkled effects of various kinds may be obtained. After the caustic soda paste has been printed on the cloth, it is run for a short space so as to give the necessary time for the completion of the mercerising, but it is not dried as in ordinary processes of printing, as the drying in of the strong caustic soda solution would be injurious to the cotton. After the action of the caustic soda is finished the printing paste is washed off and the goods are soured by treatment with a dilute solution of acetic or sulfuric acid. As the mercerised fibers in this case are not maintained under tension, there will not be any luster

developed, but as the object of the process is to cause the cloth to shrink in pattern effect, the question of luster does not enter into the case.

Other methods of crêping may also be employed; such, for example, as that of first printing on a paste containing a substance capable of acting as a resist against the action of the caustic soda. Neutral protective materials, such as China clay, or acid-bearing substances, such as alum, may be used. Under such conditions, by treating the printed cloth with a mercerising solution of caustic soda, only those parts which are not protected by the printing will be mercerised and will shrink, leaving the other parts in their natural condition, after the paste has been washed off.

By printing with a resist paste and then mercerising under tension, it is possible to obtain a fabric that is mercerised and lustered in pattern effect on an unmercerised and lusterless background, giving rise to a damask effect.

A variation in the usual mercerising process is suggested in a patent of Heberlein.[1] The yarn or cloth is impregnated with a solution of 300 grams of starch in 10 liters of caustic soda lye at 33° Tw., the materials being immersed in this solution for about ten minutes in the stretched condition, and then washed with water, dilute acid and again with water. The cotton treated in this manner is said to acquire a silky luster and a stiffness which is not lost by subsequent washing or dyeing. The process was suggested as useful for the manufacture of polished yarns. This process also contains the germ of the methods subsequently discovered by this same inventor of giving cotton fabrics a permanently stiff finish by mercerising and then treating with sulfuric acid.

Knecht recently described a new process of mercerising, which depends upon the action of hydrochloric acid of particular strength (37° to 38° Tw.). This, he said, not only brought about a shrinkage of the cotton, but also an enormously increased affinity for the majority of coloring matters. The duration of the action was thirty seconds, and it did not, he said, bring about any "tendering" or deterioration of the fiber. Knecht thought that the reason why the action of such a common reagent as hydrochloric acid had never been detected before was because the particular strength of hydrochloric acid to which he referred was not commercial, and its behavior toward various substances had not been particularly studied. The reagent, he observes is cheap, and the washing-out of the acid may be completely effected in a minimum of time.

28. Swiss Finish or Mercerising with Acid.—This finish, which makes the cotton translucent, lustrous, and stiff, has been chiefly developed by the Swiss chemist Heberlein. The starch-like stiffness of the fabric is permanent against the action of repeated washing or laundering. The

[1] *Brit. Pat.* 27,529 of 1898.

treatment consists essentially of mercerising the cotton fabric (usually voile, organdie, or other light-weight material) with strong caustic soda liquor and then subjecting it to the action of a strong sulfuric acid solution, and finally removing the acid.

Mercer, in the year 1844, and others later, have observed that if concentrated sulfuric acid is allowed to act on cotton the fabric acquires a parchment-like character. This effect is simply the extension of the general reaction of strong sulfuric acid on cellulose, which had long before been observed in the case of paper and which has been commercially employed in the manufacture of parchment paper. According to Mercer this effect is obtained by the use of sulfuric acid of 49.5° to 55.5° Bé., and he observed that the cotton apparently underwent a chemical change that made it more susceptible to the action of certain dyes. It was apparently Mercer who was the first to observe the effect of this acid treatment on paper. By treating paper with sulfuric acid of various strengths from 115° to 125° Tw. and at a temperature of 50° F. he found the paper to be translucent and considerably strengthened. The paper used could be either sized or unsized. By impregnating it with gelatine and drying previous to dipping it in the acid, he obtained, after washing and drying, a " very fine white paper, which folds quite easily," to quote his own remarks. This " mercerised " paper was probably regarded by Mercer rather as an article of curiosity than as one of practical value; but a few years afterward it became manufactured extensively by others as the useful material now known as " parchment " paper. It is customary to employ unsized paper and to immerse it in sulfuric acid diluted with one-third to one-quarter its volume of water and cooled. The cellulose fiber is rapidly attacked, the paper becoming transparent owing to the swelling and gelatinisation of the fibers, and after this the reaction quickly becomes one of solution. But if the time of treatment is properly regulated and the treated paper rapidly washed in water, the acid compound is decomposed, and the resulting gelatinous hydrate of cellulose is fixed as a constituent of the paper. When the product is exhaustively washed and dried it gives a tough translucent sheet. The changes which the cellulose undergoes in this treatment have been studied by Guignet.[1]

The use of sulfuric acid was included in Mercer's Patent of 1850 for " Improvements in the Preparation of Cotton." The action of this acid, like that of caustic alkali, varies considerably with the strength, temperature, and time allowed for action. Weak acid as well as strong produces disintegration of the fiber, but exposure for a few minutes to acid of 104° to 125° Tw., at ordinary temperatures, produces a modification of the fiber without impairing its tenacity. If the object is to enhance the

[1] Soluble and Insoluble Colloidal Cellulose and Composition of Parchment Paper, *Comptes rendus*, vol. 108, p. 1258.

color receptive power of cotton cloth without injury to the fiber, Mercer considered the best strength to be about 104° Tw. at 50° to 60° F. The cloth, which should be in a condition to absorb liquids quickly, was passed over and under rollers so as to be in the acid for one minute, then through squeezers, and finally washed by a series of rollers in water. Sulfuric acid of 104° Tw. produces very little immediate effect. Mercer regarded the effective hydrate to be the " terhydrate " ($H_2SO_4 \cdot 2H_2O$) of 125° Tw., but acid of that strength was found by him to be too energetic for practical use under the conditions with which he operated. He made the following observations regarding the action of sulfuric acid of different strengths on cotton and paper: " Three stages, or perhaps more, may be recognised in the action of sulfuric acid. The first action seems to be the expansion and rupture of the fiber; to effect which the strength of the acid should be about 110° Tw. at a temperature of about 50° F. When washed and dried the cloth is not stiff as is the case with stronger acid, but very soft and feels similar to glove leather. It is not much contracted, and can be easily stretched to its original size. It is very white and its power of receiving color is greatly augmented. It is to cloth of this character that my patent relates. The next stage is exhibited with acid of about 114° to 115° Tw., at the same temperature. This strength causes considerable contraction of the cloth. When washed and dried under pressure between folds of bleached cloth, it is stiff and white, having the appearance of being impregnated with a dense white precipitate. It cannot be stretched to its original dimensions. If the cloth is impregnated with milk and dried before being immersed in the acid, it looks still whiter and more beautiful. Sulfuric acid stronger than the above—namely, from 116° to 125° Tw., at the temperature of 50° F. produces another marked effect. With this the cloth becomes semi-transparent. It is stiff and much contracted. If a design is first penciled or printed with a protecting paste of albumen, solution of casein, or thick gum water, and dried before being put into the acid, the design is preserved and a very pleasing effect may be produced. When paper or cotton is digested for a little time in acid not stronger than 115° Tw. at common temperatures, it dissolves, forming a thick pasty liquid, which, when poured into water, gives a white precipitate something like boiled rice, very soluble in caustic soda."

Blondell [1] has also observed that sulfuric acid of 90° to 106° Tw. imparts to cellulose the capacity of being brightly colored with Methyl Blue, whereas a parchmentising effect only results when the sulfuric acid is of a concentration of from 116° to 125° Tw.

The work of Georges Heberlein, of Switzerland, has been detailed in quite an array of patents, among which the following are the more important: *Ger. Pats.* 280,134, 290,444, and 294,571; *Fr. Pats.* 468,642, 468,821,

[1] *Bull. Soc. Ind. Rouen,* 1882, pp. 438 and 471.

and 481,561; *Brit. Pats.* 12,559 of 1914, 13,129 of 1914, and 100,483 of 1915; *U. S. Pats.* 1,392,264 and 1,392,265.

Heberlein states that he has discovered that sulfuric acid of a concentration of 51° Bé. (109° Tw.) and above produces on the cellulose an entirely different effect than that produced thereon by an acid whose concentration is below 51° Bé. Although a more highly concentrated sulfuric acid imparts to cotton fabric after a few seconds' action a typical parchment-like appearance, such an acid of, for example, 50° Bé. (106° Tw). even after acting for fifteen minutes, will not cause a like alteration of the cellulose, and in contradistinction to the effect of a slightly stronger acid, the fabric will not be weakened by even longer action. Heberlein also states that the action of sulfuric acid of a concentration under 51° Bé. (109° Tw.) will be much more intensive and will impart to cotton entirely new qualities if the cotton has been previously mercerised, because it is rendered thereby more susceptible to the action by the acid. If cotton fabric which has been mercerised and also preferably bleached, be subjected to the action of sulfuric acid of from 49° to 50½° Bé. (103° to 108° Tw.), the mercerising luster disappears and instead of the transparency obtained with the higher concentrations, the fabric assumes a fine crêpe-like nature, whereby it appears thicker, fuller, and more wool-like, softer, and generally improved in its entire quality, and takes on the character of a fine, thin woolen material. This is the novel finishing effect introduced by Heberlein.

The process may be applied to the treatment of plain, patterned, or embroidered fabrics. Pattern effects may also be produced on plain fabrics by printing sulfuric acid of 50° Bé. (106° Tw.) on a mercerised cloth and washing out the acid after the action has been completed. These may also be printed on a suitable resist, such as a gum thickening, and then the entire fabric may be dipped into sulfuric acid of the concentration mentioned. At the points where the acid has acted the cloth will exhibit the effect mentioned above, so in this manner designs or patterns of a combination of lustrous mercerised cotton cloth with a dull wool-like fabric may be obtained.

The time that the sulfuric acid should be allowed to act will depend on the nature of the fabric being treated; in some cases only a few seconds are required, while in others several minutes will be necessary.

The fabric may also be first treated with the acid, washed, and then without stretching, mercerised with caustic soda. Heberlein also states that the sulfuric acid may be replaced by phosphoric acid of 55° to 57° Bé. (123° to 130° Tw.), or with hydrochloric acid of sp. gr. 1.19° at low temperature, or with nitric acid of 43° to 46° Bé. (85° to 94° Tw.), or with zinc chloride solution of 66° Bé. (168° Tw.) or with copper oxide ammonia

solution with a short reaction period. But the best effects are claimed to be obtained with the use of sulfuric acid.

In *U. S. Patent* 1,392,265, Heberlein describes the use of sulfuric acid in concentrations over 50.5° Bé. (108° Tw.) for the purpose of producing a fabric having a parchmentised appearance, especially one having greater transparency. He uses mercerised cotton for this purpose as it has greater reactivity with the acid. Heberlein states his process and the effects as follows:

"It is a characteristic of cotton fabric treated according to my process, that it is really quite transparent, giving the effect or appearance of a high grade transparent 'organdie,' and that the fibers are bright and clean, and give to the fabric a bright or sheen effect, and a smooth, finished appearance in contrast to the dull, rough, unfinished truly parchmentised effect which is characteristic of cotton fabrics produced by simply treating the ordinary cotton fabric with sulfuric acid, as had been known prior to my above set forth process. It is also a characteristic of fabrics treated according to my process, that their chemical structural change is permanent; namely, will withstand repeated laundering so that the goods may be laundered without eliminating or materially altering the said characteristics, and this greatly enhances their value.

"Where the entire fabric is treated according to my above process, the heretofore described transparent effect is, of course, produced all over the fabric so as to provide a transparent fabric of pleasing effect which has a bright clean appearance with somewhat of a sheen resembling high grade transparent organdies; and where only portions of the fabric are treated according to my invention and the other parts remain as unaltered mercerised fabric, so as to produce pattern effects, of course the mercerised parts remaining untreated retain the physical characteristics of mercerised cotton, in that they are soft, glossy and opaque, and show up in striking manner in contrast to the transparent portions.

"I have also found that a still more enhanced transparency of the cotton fabric can be obtained by an improved process, according to which sulfuric acid of over 50½° Bé. and concentrated caustic alkali are caused to act upon cotton fabric several times alternately, the sulfuric acid being always allowed to act only for a few seconds.

"In order to obtain this greater or enhanced transparency as compared with that obtained by my first mentioned process, it is necessary that one of the two agents be applied at least twice with an intermediate treatment of the other, as for example, caustic soda—sulfuric acid—caustic soda, or *vice versa*. In between the reactions the goods must be well washed, and subsequently dried.

"If cotton fabric treated with concentrated caustic soda is subjected for the second time to the same treatment no further change takes place in the same. That is, the second caustic treatment remains without effect on the fabric. Cotton fabric behaves in similar manner toward repeated treatments with concentrated sulfuric acid. If, however, the cotton fabric that has been mercerised has been subsequently exposed to the action of concentrated sulfuric acid, and then to caustic soda, the caustic soda reacts anew upon the fabric and effects a further change. The same is true if the first treatment is with the concentrated sulfuric acid, and then the next treatment with caustic soda and another treatment with sulfuric acid. In each such alternate treatment the acid or alkali, as the case may be, will again work or be effective upon the fibers of the fabric to alter them further. The alternate treatment with acid and alkali can be several times repeated.

"It is evident that varied degrees of transparency are obtained according to the number of manipulations or alternate treatments. Modifications in the quality of the fabric can also be obtained by either stretching the same more or less during the treatment, or by having the same more or less shrunk in the longitudinal and cross directions.

"Finally transparent pattern effects may be obtained by printing the alkali or the acid at one or more of the operations only upon particular portions of the fabric, or by printing on particular portions of the fabric a resist (for instance, gum thickening) either at the commencement of the treatment or between the first and the second or between two successive operations, the said resist preventing a further reaction of the alkali or the acid. For example, it will be obvious from the above that if the aforesaid pattern effect of glossy mercerised portions and of transparent portions is to be produced, the fabric can be treated with alkali all over, then a resist of the design put on and then the background is treated with acid and then with alkali."

The product described has become a very important article of trade and is generally known as " permanent finish " Swiss voile, or the like. It is also being made in the United States, presumably under license from the Swiss inventors. The chief problem, however, to be solved in the manufacture of this material is not that of the requisite chemical treatment, which had already been more or less definitely described by Mercer a good many years ago, but the manner of handling the goods in the treatment so as to obtain a commercial product without injury to the fabric. This problem is an intricate one of mechanical engineering, and it has been more by reason of the proper solution of these engineering problems that the process has become commercially available than through the " discovery " of the chemical treatment.

In *U. S. Patent* 1,395,472, Bosshard, another Swiss chemist, describes the use of nitric acid and of nitro-sulfuric acid. It may be noted that the use of nitric acid in this connection has already been mentioned by Heberlein in *U. S. Patent* 1,392,264. The commercial possibilities offered by the use of nitric acid are small compared with those obtained by the use of sulfuric acid, and it is doubtful if the process has ever been successfully operated on a large scale. As a matter of patent literature, however, the work of Bosshard is interesting and may be given as stated by the inventor as follows:

"It is well-known fact that the action of concentrated mineral acids on cotton fabrics causes the latter to assume a transparent parchment-like appearance. It has been established that transparent effects on cotton fabrics may be obtained by treating the fabrics alternately or subsequently with sulfuric acid of from 49° to 51° Bé. and with concentrated alkaline lyes.

"Furthermore, it is already known to replace sulfuric acid of from 49° to 50° Bé. by cooled hydrochloric acid of a specific gravity of 1.19, or by nitric acid of from 43° to 46° Bé., or by a zinc chloride solution of 66° Bé. at a temperature of from 140° to 170° F. or by a solution of cupric ammonia.

"If nitric acid of a concentration of more than 42.3° Bé. (sp. gr. 1.415) or sulfuric acid of a concentration of more than 49° Bé. (sp. gr. 1.515) be caused to act on cotton

a process takes place which is similar to the mercerising by means of concentrated alkaline lyes and wherein a swelling of the fibers, shrinkage and increase of strength takes place. Bleached and mercerised cotton fabrics which are treated with such an acid assume a gelatinous parchment-like appearance and show a considerably stronger affinity to direct acting coloring matters. According to Knecht,[1] the treatment with nitric acid of 42.3° Bé. or more causes, besides a weak nitrification, the formation of a very unstable cellulose-ester which decomposes by the action of the water similar to an alkaline cellulose. If nitric acid of a specific gravity of above 1.415 (42.3° Bé.), or sulfuric acid of a specific gravity of above 1.515 (49° Bé.) is caused to act on bleached or mercerised cotton fabrics, these fabrics assume after a short time a gelatinous parchment-like appearance and after a strong tentering; that is, stretching with jigging motion of the treated fabrics, they assume a transparent appearance.

"The present invention is based on the observation, that the above described gelatinous, parchment-like or transparent effects of strong nitric acid or sulfuric acid on bleached or mercerised cotton fabrics are considerably increased if, instead of using such an acid separately, a nitro-sulfuric acid of from 48° to 50½° Bé. and cooled down 32° F. or below is used, that is, a liquid obtained by mixing nitric acid of from 40° to 41° Bé. (at a temperature of 60° F.) and sulfuric acid of from 55° to 58° Bé. (at a temperature of 60° F.).

"If a nitro-sulfuric acid cooled down to 32° F. or below within the lower limit of minus 4° F. and consisting of 1 part by volume of sulfuric acid of from 55° to 58° Bé. and 1 part by volume of nitric acid of from 40° to 41° Bé. is caused to act upon a bleached or mercerised cotton fabric, the fabric assumes after five seconds a gelatinous parchment-like appearance whereby the fibers swell and shrink in the longitudinal and transverse directions. The above described morphological modifications of the fabric can be varied at will by using nitro-sulfuric acids of different concentration.

"If a concentrated nitro-sulfuric acid composed of for instance 1 part by volume of sulfuric acid of 57° Bé. and 1 part by volume of nitric acid of 41° Bé. is used strong parchment-like effects result which, after a tentering or stretching with jigging motion of the treated fabric, change over into transparent effects which may be increased by a subsequent mercerising of the treated fabric.

"If bleached or mercerised cotton fabrics are printed on with reserves the treatment of these fabrics with concentrated nitro-sulfuric acid allows of obtaining transparent pattern effects. It will be noted that the treatment of the fabric takes place at a temperature below atmospheric temperature and while the fabric is kept stretched. By controlling the temperature and keeping it low the character of the transparent fabric can be varied from a hard feeling fabric at the higher temperatures to a soft feeling fabric at the lower temperatures. On the other hand, if the concentration be but slightly lowered with a corresponding increase in the length of time required for nitration by reason of the lesser concentration, wool-like effects will be obtained, the fabric in this instance not being strongly stretched to allow free deformation of the fibers."

In this same connection may be mentioned the work of C. Schwartz,[2] referring to a process for converting cotton fabrics into a material having a wool-like appearance. His process is based on a treatment with starch and nitric acid.

A paste is prepared by heating together 40 kilograms of maize starch, 75 liters of water and 75 liters of acetic acid. The textile is dressed with

[1] *Brit. Pat.* 37,459 of 1904.

[2] *U. S. Pats.* 1,400,380 and 1,400,381.

this paste, dried, treated for three to five minutes with 72 percent nitric acid at a temperature of 60° to 70° F.; the excess of acid is pressed out, and the textile material is passed into a 10 percent solution of sodium bisulfate and washed with water.

In another process of Schwartz the fiber is impregnated with a slightly ammoniacal solution of casein, containing 10 percent of the latter, dried, and submitted for some time to the action of formaldehyde vapor; it is then treated for two minutes with 75 percent nitric acid at the ordinary temperature, squeezed or pressed out and washed. The yellowish color of xantho-proteid developed by a secondary reaction may easily be removed by treatment with weak carbonate of soda.

The commercial developments of these processes are still in a state of growth but sufficient has been accomplished to show that from the processes described in the patents of Heberlein, Bosshard and Schwartz coupled with the design and construction of suitable machines and accessory apparatus to properly carry out the processes in a commercial form there is much to be hoped for in the gradual perfection of a process of treating or finishing cotton fabrics which will give us a line of useful and novel fabrics which will be a great addition to the industry. Mercerising has now become a universal and well established process in the converting of cotton goods and has brought into existence many new fabrics which have proven of great value and utility. It is quite possible that the new methods of treatment which have here been outlined may prove in time as valuable as the mercerising process itself. When we consider the fact that this acid treatment process also originated in the fertile brain of John Mercer, we can appreciate in some measure what a large debt the textile industries, and all those other industries connected therewith, owe to the great textile chemist of seventy years ago.

CHAPTER XX

THE MINOR SEED HAIRS

1. Bombax Cotton.—Besides the cotton derived from the ordinary species of the cotton plant (*Gossypium* family), there is a very similar seed-hair fiber obtained from a plant known as the *cotton-tree* and belonging to the *Bombaceæ* family. The fiber is known in trade as *vegetable down* or *bombax cotton*. It grows almost exclusively in tropical countries. The fiber is soft, but rather weak as compared with ordinary cotton; in color it varies from white to a yellowish brown, and it is quite lustrous. The fibers have a length of from 10 to 30 mm., and a diameter of from 0.020 to 0.045 mm. Owing to its weakness and lack of elasticity, bombax cotton is not used by itself as a textile fiber; it is sometimes mixed with ordinary cotton and spun into yarn, but it is principally used as a wadding and upholstery material.

In its physical appearance, bombax cotton differs from true cotton in not possessing any spiral twist and showing irregular thickenings of the cell-wall; the fiber usually consists of one cell, though occasionally it may have two. Unlike true cotton, the fiber does not grow directly from the seed, but originates at the inner side of the seed-capsule.

There are several varieties of plants from which bombax cotton may be obtained.[1] In Brazil it is obtained from the *Bombax heptaphyllum*

[1] Dodge gives the following list of plants that yield so-called vegetable silk:
Asclepias syriaca and *A. incarnata* (milkweed).
Asclepias currassavica (platanilo of Venezuela).
Bombax ceiba.
Bombax cumanensis (lana del tambor of Venezuela).
Bombax malabaricum.
Bombax munguba.
Bombax pubescens.
Bombax villosum.
Calotropis gigantea.
Chorisia insignis and *C. speciosa*
Cibotium menziesii (pulu fiber, not a true vegetable silk).
Cochlospermum gossypium.
Eriodendron anfractuosum (commercial kapok).
Eriodendron samauma.
Epilobium angustifolium (fireweed).
Ochroma lagopus (balso; also known as the corkwood tree).

and *B. ceiba*, and the product is known as *Paina limpa* or *ceiba cotton*. This is also produced in the West Indies and other parts of tropical America.

All the varieties of Bombax cotton are very similar in appearance and properties, and it is practically impossible to discriminate between them with any degree of certainty. In *Bombax ceiba* the fiber has a length of from 1 to 1.5 cm., while in *B. heptaphyllum* the fiber length is from 2 to 3 cm., being by far the longest and strongest variety of bombax cotton.[1] *B. malabaricum*, of South Asia and Africa, has fibers from 1 to 2 cm. in length; this latter is known in India as *Simal* cotton or red silk-cotton.[2]

Other varieties of *Bombax* plants are *B. cumanensis* of Venezuela, giving a product known as "*lana del tambor*" or "*lana vegetale*"; *B. pubescens* and *B. villosum* from Brazil; *B. carolinum* from South America; *B. rhodognaphalon* of West Africa, the fiber of which is known as wild kapok and is used largely for the stuffing of pillows and mattresses.

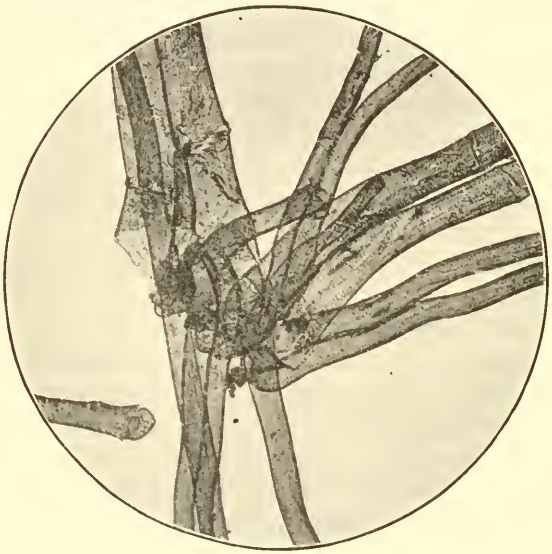


Fig. 251.—Bombax Cotton. (Herzog.)

Cauto cotton of Cuba is the fiber obtained from a cotton tree. This cotton is of a slightly yellowish tint; the best fiber is of $1\frac{1}{8}$ to $1\frac{1}{4}$ in. staple, and is said to be as strong as Sea-island cotton. The plant is perennial, thus differing from the American cotton which is an annual crop. The tree grows for upwards of fourteen years, and the average tree yields 2 to 3 lbs. of seed-cotton the first year, and fully 3 lbs. the second year; about one-third of this is lint. Attempts have been made in Cuba to grow Egyptian and Sea-island cotton but without success on account of insect attacks.

The microscopical characteristics of bombax cotton are as follows: The fiber consists of a single cell, possessing a cylindrical shape, being

[1] This fiber is about the only variety of vegetable down that has ever been used in spinning.

[2] Red silk cotton is very similar, though inferior, to the ordinary kapok of commerce, for which it is sometimes substituted. It is used principally as a stuffing material in upholstery as the fiber is too short and soft to be spun

rather thick at the base and tapering gradually to the point. The base of the fiber is frequently swollen and exhibits a lace-like structure (Fig. 251). The cell-wall is usually very thin, occupying not more than one-tenth the width of the fiber, while the cuticle is well developed. The cross-section is circular and not flat, as in the case of cotton, and is from 20–40 microns broad. The inner canal is partly filled with a dried-up protoplasmic membrane.

In its chemical constitution bombax cotton differs from ordinary cotton in containing a certain amount of lignified tissue, consequently it furnishes a yellow coloration when treated with aniline sulfate or with iodine and sulfuric acid, and by these tests it may readily be distinguished from true cotton. Owing to its lignified nature the fibers also swell but slightly when treated with Schweitzer's reagent. The fiber from the *Bombax ceiba* is distinguished by its decidedly yellowish color.

None of the varieties of the bombax cottons is a pure white, but vary in color from pale yellow to brown. The *paina limpa* is the lightest in color.

2. Kapok.—The seed-hairs of the *Eriodendron anfractuosum* (or *Bombax pentandrum*) are very similar to the preceding varieties of bombax cotton. It gives the product known in Holland as *kapok*.[1] In both their physical

[1] The term kapok is improperly applied to a large number of silky-fibered plants which are similar in appearance, but widely different in their properties and origin. The true kapok fiber comes from the kapok tree (*Eriodendron anfractuosum*). The chief countries of production are the Dutch Indies and Java. Kapok and similar fibers are grown in Ceylon, British India and Central America. Experiments are being made in the raising of the plant in German New Guinea and German East Africa. The fiber has been known in the trade for years and is imported in limited quantities. The kapok tree is grown extensively in Java where it forms great rows along the roads. The following statistics are given for the Java trade in kapok for the year 1921:

To	Exports in Tons,
Holland	4,436
Great Britain	223
Germany	....
Elsewhere in Europe	327
United States	10,078
Australia and New Zealand	1,967
Singapore	282
Japan	231
Elsewhere	41

It will be seen, therefore, that the United States is the largest consumer of kapok. It is employed principally as a mattress filler, having great advantages in this respect. It is very resilient and very light; a mattress of 3 by 6½ ft. requires only 17 to 20 lbs. of kapok, against 26 to 29 lbs. of horse-hair, 33 to 35 lbs. of seaweed, or 30 to 60 lbs. of straw. Furthermore, it will not retain moisture, which is very important for bedding in moist climates. Kapok mattresses are also very sanitary, being quite vermin-proof. With regard to the buoyancy of Java kapok it will carry from 20 to 30 times

appearance and chemical properties it is almost impossible to distinguish between kapok and *ceiba* cotton. Kapok is obtained from South Asia and the East Indies, and is very extensively used as upholstery material, and also for the stuffing of life-saving belts on account of its low specific gravity. It is stated that in the compressed condition kapok can support about thirty-six times its weight in water, and it has the advantage over cork of drying quickly. Kapok has also been used in surgery as a substitute for absorbent cotton.[1]

In the preparation of kapok the bare fruit is picked from the tree by the natives and broken open by pounding with mallets. The seed and fiber is removed and dried in the sun. The drying process is carried on inside of a wire netting in order to prevent the fiber from being blown away. Drying by artificial means is not employed. The fiber is separated from the seed by hand. The seed with the fiber is thrown into a basket and stirred by hand with a short stick. The heavy seed sinks to the bottom and the fiber is removed from the top. As will be readily understood, this is a slow and expensive process. Attempts have been made to invent a machine for removing the fiber, but without success owing to its brittle nature. Of late years there has been much adulteration of the kapok fiber by mixing with low grades of cotton and cotton waste. The fiber is packed in square bales at a pressure of 150 to 450 lbs. to the inch. The bales are covered with jute and fastened with iron bands. Owing to the importance of kapok cultivation in Java the planters in that colony have tried to protect their trade by marking the product "Java kapok,"

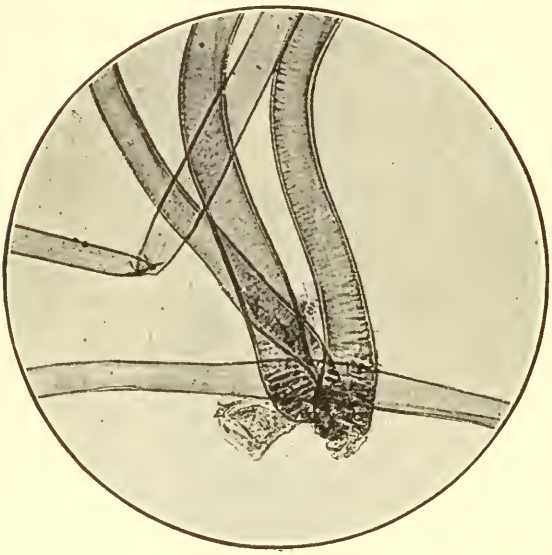


Fig. 252.—Root Portion of Kapok Fiber. (Herzog.)

its own weight in water, while Indian kapok will carry only 10 to 15 times its own weight. Java kapok also does not lose its buoyancy by immersion in water; on a thirty-days' immersion test it lost only 10 percent of its buoyancy.

[1] The Chemnitzer Aktienspinnerei of Chemnitz, Germany, manufacture kapok into a yarn possessing a marked silk-like appearance. The material may be dyed in any desired color, and may be employed in the weaving of quite a variety of fabrics.

and having each bale stamped to indicate the quality as a guarantee against adulteration.

Owing to the inflammability of kapok many fire insurance companies have refused to take risks on establishments in which this material is used; others having accepted the risks only at very high premiums. The kapok seed yields about 25 percent of oil, which is used in the manufacture of soap. The seed from which the oil has been pressed is used for fertilising the land and for feeding cattle.

Kapok, on account of its great buoyancy and freedom from water-logging, has been employed to a large extent in recent years in the manufacture of life-buoys, life-belts, waistcoats, seat covers, and other appliances used for saving life at sea. Java kapok, which is the kind usually specified in navy requirements, consists of the seed-hairs of *Eriodendron anfractuosum*, and, although this tree occurs, in India, most of the Indian kapok is obtained from the so-called cotton-tree, *Bombax malabaricum*, and therefore does not in this respect meet the requirements of most specifications. The seed-hairs of *Calotropis procera*, known as Akund floss, are also collected in India, and sometimes become mixed with Indian kapok.

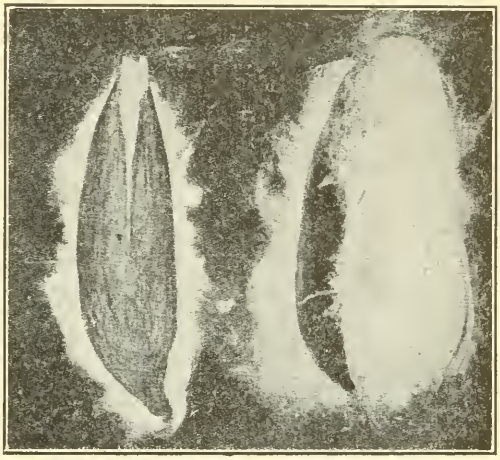


Fig. 253.—Seed Capsules of Kapok.

In order to investigate the question of the natural volume of Indian kapok as compared with that of genuine kapok, the following experiment was made: 50 grams of floss were placed in a cylindrical glass jar, a light stiff cardboard disk was then laid on the floss, and a 500-gram weight placed on the card; after standing some time, the height of the column of floss was measured. The following figures, given in the *Bulletin of the Imperial Institute*, were obtained as a result of repeated experiments:

	Natural Volume.
Java kapok	100
Indian kapok (machine-cleaned)	125
" " (commercial sample No. 1, referred to above)	93
Akund floss	100

In experiments to determine the buoyancy of the Indian kapok the results obtained on a large scale with 24-oz. samples of floss agreed well

with those obtained in the small-scale trials, except in the case of the weights supported by the floss after rough treatment. They indicate that although Indian kapok appears to be liable to contain more adventitious matter (e.g., sand, leaf, and pieces of pod) than commercial Java kapok, there is no apparent ground for condemning its use in life-saving apparatus provided that it is in a reasonably clean condition.

Akund floss, on the other hand, is distinctly inferior to kapok in buoyancy, and in one of the trials its buoyancy after twenty-four hours' immersion was not sufficient to meet the Board of Trade requirements; further, it will not stand rough usage, and rapidly becomes waterlogged. It should, therefore, be excluded from use in life-saving appliances, and its use restricted to upholstery, etc., where buoyancy is not required.

The use of kapok and its substitutes underwent considerable expansion during the World War. In view of the utilisation of kapok and other flosses for life-saving appliances, an investigation has been carried out by Cross and Bevan, with the object of devising a rapid method for determining the approximate value of representative samples.[1]

It has usually been assumed that the impermeability of the material to water is due to the presence of such constituents as oil, wax, and resin in the wall of the fiber; but it has now been found that this is not the case. The amounts of such constituents vary considerably in different samples, but the variations do not show any correlation with the resistance of the fiber to the admission of water, and the resistance is not appreciably affected by the removal of these substances. Three tests are recommended for the rapid determination of quality in the laboratory. The first of these is observation of the degree of lignification of the fiber by the phloroglucinol test; the best samples do not give any reaction with phloroglucinol, but the lower qualities give a reddish brown or even a magenta-red coloration, typical of lignocelluloses. The second test consists in the microscopical measurement of the diameters of the fibers; the more uniform the diameter, the higher is the quality of the material. The third test is carried out by floating the fiber on the surface of aqueous alcohol, of sp. gr. 0.928, and determining the relative rates of wetting and sinking of the different samples. Particulars are given of the flotation and resistance to submersion of certain appliances made with kapok. The life-saving jacket tested contained 700 grams of kapok, and, since the average floating power of the compressed fiber is equal to fifteen times its weight, the jacket, when submerged, exerts a lifting power of 10.5 kilograms. When placed in water and partially submerged by a weight of 9 kilos, the jacket still supported an extra load of 1.3 kilos after seventy-two hours; after one hundred hours it still required an addition of 1.0 kilo

[1] *Jour. Soc. Dyers & Col.*, 1916, p. 274.

to submerge it, and after one hundred and ninety-two hours the weight required was 0.9 kilo.

Attempts to spin the lustrous and attractive fiber of kapok had been frustrated by the extreme brittleness and smoothness of the fiber, until the late Emil Stark of the Chemnitzer Aktienspinnerei succeeded after years of experimenting in perfecting a process by which it became possible to spin kapok to as fine as 8's yarn, cotton count. A mixture of kapok and cotton can be spun to 20's, and mixed with wool or silk waste has been spun to 10's. The Stark process is likewise suited for spinning fibers similar to kapok, particularly the *Calotropis* from southern Asia and Africa, and which, owing to its extreme length can be worked more easily than the regular kapok. In the Stark process, the fiber is treated with a solution, such as ether, carbon disulfide, and also with boiling water. This treatment dissolves the substances that may have adhered to the fiber, which loses its luster by reason of the resulting shrinkage.

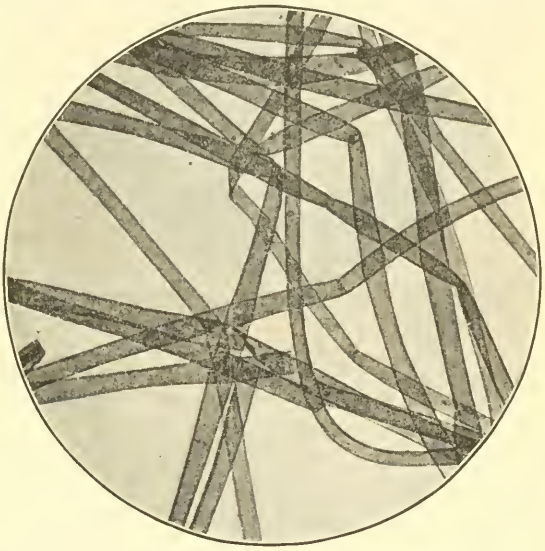


FIG. 254.—The Kapok Fiber. (Herzog.)

When examined microscopically kapok is seen to have a tapering cylindrical form, the fiber consisting of a single cell with a bulbous base (Fig. 252). It is soft and lustrous but deficient in elasticity, hence is too brittle for purposes of spinning. The fiber resembles a smooth transparent structureless rod, frequently doubled over on itself (Fig. 254). Like the bombax cottons, kapok contains lignocellulose, hence gives the yellowish brown coloration with iodine and sulfuric acid. The following are analyses of kapok from different sources:

	Lagos Kapok, Percent.	Java Kapok, Percent.	Seychelleo Kapok, Percent.
Moisture	9.9	10.9	10.00
Ash	2.8	1.3	2.08
Cellulose	50.3	63.6	61.30

Kapok has a very wide lumen in contrast with a very thin wall. It is very brittle and cracks easily. As a result kapok is easily broken when subjected to the spinning process, owing to the pressure and twisting to which it is necessarily subjected. The *Calotropis* fiber has a similar structure, but exhibits more distinct longitudinal lines (Fig. 255). In a mixture of kapok and cotton under the microscope (Fig. 256), the wide, transparent and structureless kapok fiber is easily distinguished from the cotton. A mixture of the two is, therefore, readily detected.

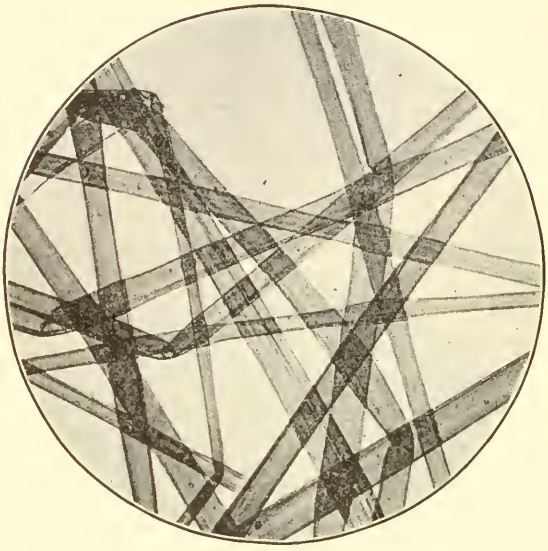


Fig. 255.—The Calotropis Fiber. (Herzog.)

The kapok fiber has a length of 0.3 to 1.25 ins., an average of 0.7 in., and a diameter of 0.0012 to 0.0014 in. It has a beautiful silk-like luster, is yellowish brown and very light. Small tufts of the material are whirled in the air at the slightest draft. The cross-section of the fiber is generally circular or oval in form (Fig. 257), with a very thin wall. The resistance of the thin wall to natural conditions is fairly high, but it offers less resistance to the wear and tear of working into yarn. The cross section sometimes shows the fiber to be flattened, a result of unripe or dead fibers. The *Calotropis* fiber has a length of 0.7 to 1.5 ins. and a diameter of 0.0006 to 0.0016 in. In outward appearance it is similar to kapok. The cross-section is usually similar to that of kapok, being round and oval.

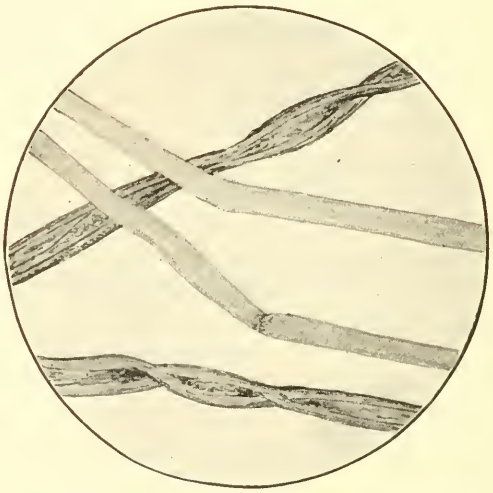


Fig. 256.—Mixed Kapok and Cotton Fibers. (Micrograph by author.)

The following interesting commercial data concerning kapok are given in a U. S. Consular Report: Java exports about seven-eighths of the total export of kapok from the East Indies. Although the greater part of the cultivation of this tree is native-owned, there are a number of estates under European management. On these estates the kapok tree is mostly interplanted with coco and coffee. When ready for export, the product is usually marked with the name of the district of origin. Kapok is well suited for stuffing of mattresses, life-belts, bandages, etc., but is also employed for spinning purposes, in the manufacture of felt hats, and of gun-cotton. It absorbs very little moisture, and, having a great buoyancy, can carry twenty to thirty times its own weight in water.

Exporters state that the United States requires first qualities only, while medium grades go to Europe and the lowest to Australia.

The Soerabaya Handelsvereeniging recognises the following broad descriptions: Good, clean, prime Madura; good, clean, prime Porrong; good, clean, prime East Java, fair average quality of the crop. A further classification is as follows: Fancy grade, with a maximum of $1\frac{1}{2}$ percent of seeds and dirt; a good marketable quality, with a maximum of 5 percent of seeds and dirt; lowest quality, with a maximum of 6 percent of seeds and dirt.

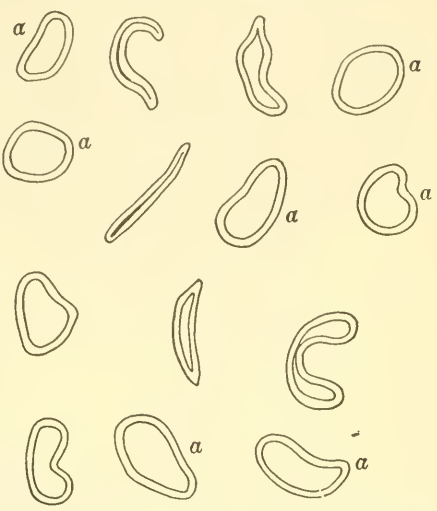


FIG. 257.—Cross-sections of Kapok Fibers.

Exports of kapok in metric tons (metric ton = 2204 lbs.) from the Netherlands East Indies to the principal countries of destination were as follows:

Principal Countries of Destination.	1913, Metric Tons.	1917, Metric Tons.	1918, Metric Tons.	1919, Metric Tons.
Netherlands	5,028	125	50	3,375
United States	1,377	5,690	4,440	9,110
Great Britain	25	1,519	34	1,165
Singapore and Penang	680	1,094	406	1,149
Australia	2,110	2,537	2,509	1,688
Total exports	10,145	11,939	9,031	17,082

3. Vegetable Down.—The hair-fibers of the *Ochroma lagopus* (from the West Indies) have a length of from 0.5 to 1.5 cm., and are thicker (6–7 microns) in the middle than at the ends. The cell-wall is much thicker than with bombax cotton, and the fibers are also more lignified than those of the latter. The walls are especially thick at the base and apex and here show the presence of granular matter (Fig. 258). The color of the fiber is dark brown. Vegetable down occurs in trade as *édrédon végétale* or *pattes de lièvre,* and the product comes mostly from Guadeloupe and Martinique. The typical fibers show a deep yellow

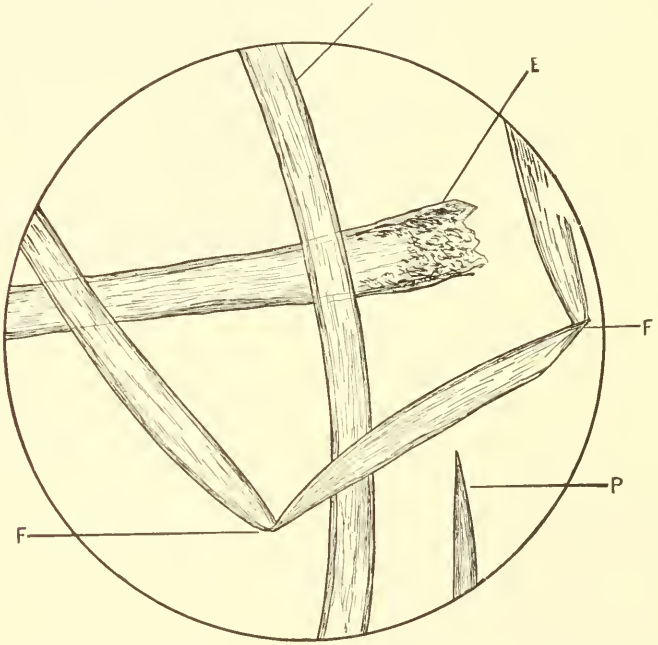


Fig. 258.—Vegetable Down. (*Ochroma Lagopus.*) (×350.) *E,* Lace-like structure at base; *F,* fiber folded on itself; *P,* point of fiber; *C,* thin cell-wall. (Micrograph by author.)

color under the microscope; others are nearly colorless, flattened, often much folded, with indistinct outline and finely striated surface. The typical fibers have a breadth of 25–50 microns. The *Ouate végétale* of the French trade is a mixture of fibers from *Bombax, Ochroma,* and *Chorisia* varieties. It is chiefly used for the stuffing of mattresses, cushions, etc.

The *Cochlospermum gossypium* of India and the *Chorisia speciosa* [1]

[1] According to Dodge, the down or vegetable silk of *Chorisia speciosa* is said to be excellent for winter mattresses and pillows. The tree is known in Brazil as *Arvore de Paina.* According to Spon, the plant yields a fiber of which textures are made

and *C. insignis* of South America also furnish fair qualities of vegetable down (Fig. 259). They are known as *Kumbi* or *Galgal*, and are used for stuffing cushions. The fibers of *C. insignis* swell up when placed in water.

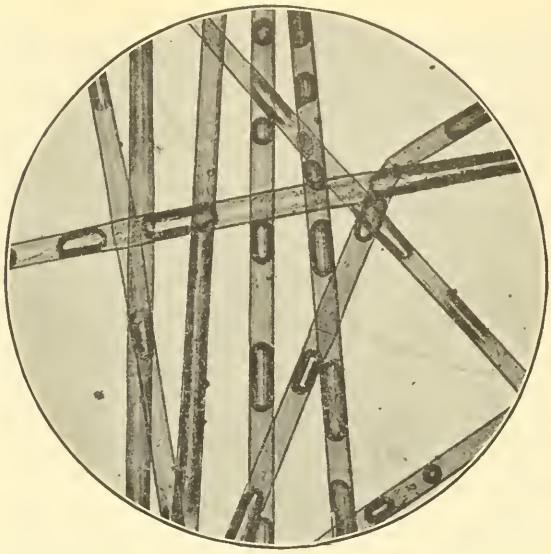


Fig. 259.—Fibers of *Cochlospermum Gossypium* Showing Air-cells in Lumen. (Herzog.)

Pulu fiber can also be classed under the general name of vegetable down. It is the hair obtained from the stems of fern-trees, more especially the *Cibotium glaucum* of the Hawaiian Islands. The fibers are lustrous, of a golden-brown color, very soft, and not especially strong. They have a length of about 5 cms., and are composed of a series of very flat cells, pressed together in a ribbon-like form (Fig. 260). The fiber is only employed as an upholstery material and is never spun. Similar fibers are also obtained from *Cibotium barometz*, *C. menziesii*, and *C. chamissoi*; the second one produces the best fiber.

Fig. 260.—Pulu Fiber from *Cibotium Glaucum*. (Herzog.)

The distinction between fibers of different varieties of vegetable down is not only difficult, but it is also without any special importance.

4. Vegetable Silk.—Another seed-hair which is utilised to some extent as a fiber is the so-called which are so much like silk in their luster, fineness and pliability as to be scarcely distinguished from it.

vegetable silk or *Asclepias cotton* (Figs. 261 and 262). Though the fiber presents a beautiful silky appearance it is entirely unsuited for the manufacture of textiles, though it is both longer and stronger than bombax cotton or kapok.

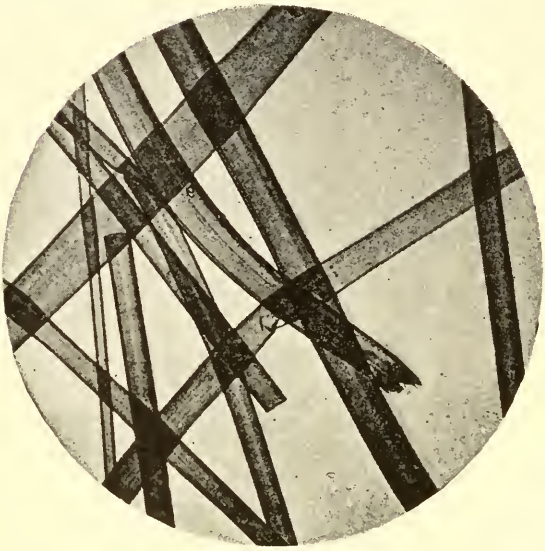


FIG. 261.—Fibers of Asclepias Vegetable Silk. (Herzog.)

This fiber is obtained from *Asclepias syriaca* and *A. incarnata* or common milkweed or silkweed. The plant grows extensively in America. The surface fiber from the seed-pods [1] is used for upholstery material.[2]

The fiber of vegetable silk is quite brittle in nature and possesses but

[1] The same plant also furnishes a bast fiber which is fine, long, and glossy, and said to be equal in strength and durability to hemp.

[2] There have been, however, spasmodic attempts by individuals to prepare fabrics from the silky fiber of the milkweed. These have been accomplished by rather laborious handwork. Dodge in *Useful Fiber Plants* states that a friend in Salem, Mass., informed him that as early as 1862, Miss Margaret Gerrish, of that city, made from the milkweed fiber some beautiful fabrics, such as purses, workbags, socks, and skeins of thread which were dyed in many colors. It also seems that this plant grows extensively in Syria, and the natives there have produced some beautiful and delicate fabrics from the fiber. These attempts to utilise the fiber, however, do not seem to have resulted in any permanent extended use and have never gone beyond the limitations of amateur handwork.

The study of textile history, however, indicates that there have been serious efforts made toward the spinning and weaving of this fiber, but that such attempts have always ended in failure. It seems that while the fiber of the milkweed is beautifully white and lustrous and is of good length and of a fineness that should make it acceptable as a spinning fiber, it possesses other qualities that completely interfere with its use in this connection. The fiber is stiff and brittle; it does not lend itself to being bent and twisted, a feature which is so essential in the spinning together of a number of fibers to make a continuous and coherent thread. Furthermore, the surface of the fiber is extremely smooth, resembling almost a glass rod in this respect; it does not possess any irregularities or twists which would allow one fiber to grip on to another when being spun. The fibers are so smooth, in other words, that they slip on one another and do not cohere, so that when twisted together into a yarn the thread has no strength but very easily pulls apart under the slightest tension.

After it was found impossible to produce a satisfactory yarn by spinning the milkweed fiber by itself, attempts were made to spin mixtures of it with other fibers, and

little tensile strength;[1] hence attempts at spinning it by itself have not proved very successful. Its chief physical quality is its high degree of luster and softness. When examined under the microscope, the fiber exhibits thickened ridges (Fig. 263) in the cell-wall which serve to distinguish it from *Bombax* cotton. These ridges or longitudinal thickenings occur from 2–5 times in the fiber; in some cases very distinct, in others scarcely noticeable. Owing to these ridges the fibers appear to have indistinct longitudinal striations, thus

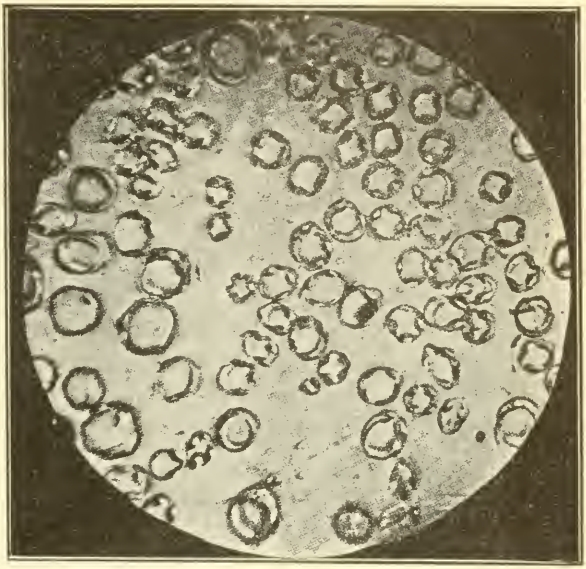


FIG. 262.—Cross-sections of Asclepias Vegetable Silk.

with some degree of success. A number of years ago a French firm employed it in this manner, mixing 20 percent of vegetable silk with 80 percent of wool. This was found to yield a rather serviceable yarn which was employed in weaving a special class of fabrics known as "silver cloth," so called from the high silvery luster produced by the milkweed fiber.

Outside of its use as a spinning material, however, the milkweed fiber has had some degree of utility as a fiber for stuffing pillows, bedding and upholstery; it has also been used as wadding. This use, however, is comparatively small and has not been sufficient to encourage the cultivation of the plant for industrial purposes.

The milkweed, however, offers other possibilities as a fiber plant than that given by the silky fibers from the seed pods. It has been found that the stalk furnishes a very fine quality of bast fiber somewhat similar in character to that of the flax plant or hemp. This bast fiber has been fairly well studied, and is said to be a fine, long, glossy fiber with great strength and durability. Some authorities have claimed that the yield of fiber from the plant is about equal to that of hemp. When compared with the hemp fiber it seems to be about as strong, and somewhat finer and more glossy in appearance. Some attempts have evidently been made in Brazil to utilise this bast fiber of the milkweed, as many fine samples have come from that country, but there has as yet been no commercial record of its use in manufacture. In India it is claimed that the bast fiber has been used for the weaving of fine fabrics and also has been employed in paper making, for which purpose it should be eminently adapted. But notwithstanding all these reports and statements of observers the products do not seem to have come into commerce sufficiently to have attracted any attention, so it will be well for the time being to accept such statements rather as over-enthusiastic intentions than as actual conditions.

[1] Vegetable silk is also unsatisfactory for the manufacture of guncotton, as it burns too slowly and leaves too much ash.

distinguishing them from other seed-hairs. Each fiber consists of a single cell, usually somewhat distended at the base. It is of a yellowish-white color; the length varies from 10 to 30 mm. and the diameter from 0.02 to 0.05 mm. As vegetable silk is somewhat lignified, it may be distinguished from true cotton by giving a yellowish brown coloration with iodine and sulfuric acid, and a yellow coloration with aniline sulfate. Its micro-chemical reactions are very similar to *Bombax* cotton, though with phloroglucinol and hydrochloric acid the latter gives a dull violet coloration, while vegetable silk gives a bright red-violet coloration.

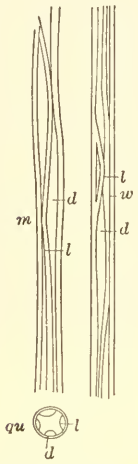


FIG. 263.—Structure of Asclepias Silk. *m*, Middle portion of fiber; *qu*, cross-section; *l*, logitudinal ridges; *d*, thin portions between thickened ridges; *w*, cell-wall. (Höhnel.)

Some attempts have been made to so alter the glossy surface of the fibers of vegetable silk that they may be spun together into textile yarns. According to Stark [1] the material may be treated with alcohol, acetone, carbon tetrachloride, gasoline, or with weakly alkaline solutions of Turkey-red oil or soap at 180° to 212° F., with the result that the outer surface of the fiber shrinks, thus making the fiber somewhat rough and at the same time removing the encrusting materials. The roughened fiber can then be spun in the ordinary manner, like cotton.[2] It would seem, however, that this treatment would take away from the fiber the very qualities of luster and silkiness that alone make it individual and attractive; if the surface were roughened, then the luster would be ruined and the author cannot see that the fiber would thus be even as valuable as ordinary cotton. It is claimed, however, that very beautiful yarns are made in this fashion and are employed in Germany in the weaving of novelty fabrics and decorative materials.[3]

There are several minor varieties of vegetable silk, chief among which are the following: *Asclepias currassavica* and *A. volubilis* from the West Indies and South America; *Calotropis gigantea* and *C. procera* of southern Asia and Africa; several species of *Marsdenia* from India; *Beaumontia grandiflora* from India, and different varieties of *Strophanthus* from Senegal.

The different varieties of vegetable silk are very difficult to distinguish from one another. They all possess a soft feel and a high silky luster. In color they vary from almost pure white to a slight orange-yellow. In thickness the fibers usually vary from 35 to 60 microns, though occasionally

[1] *Ger. Pat.* 230,142 and 230,143.

[2] See also *Ger. Pats.* 231,940 and 231,941 for the dyeing and bleaching of this fiber.

[3] See *Leipz. Monats. Text. Ind.*, 1911, p. 137; also *Elsäss Text. Blatt.*, 1911, p. 334.

they may reach 80 microns. In length they vary from 10 to 50 mm. The fiber has but little pliability or elasticity, hence is very brittle; this is due to the very thin cell-wall. All varieties exhibit the thickened ridge in the cell-wall, which gives the fiber the appearance of being uneven in thickness. In cross-section, these ridges are usually semicircular, though sometimes flat and broad. The cross-section of the fiber itself is usually circular.

Fig. 264.—Fibers of Vegetable Silk from *Beaumontia Grandiflora*. (Herzog.)

The seed-hairs of the *Beaumontia grandiflora* (Fig. 264) furnish probably the best variety of vegetable silk, as the fiber is not only the most lustrous but is also the most purely white, and furthermore it possesses the greatest tensile strength, and the fibers are easily separated from the seeds. The fibers are from 3 to 4.5 cm. in length and from 20 to 50 microns in diameter. The cell-wall is thin, being about 3.9 microns in thickness. At the base the fiber is somewhat enlarged and the walls are pierced by delicate elongated pores arranged in a row (Fig. 265). The fibers of *Calotropis gigantea* consist of thin-walled colorless cells showing pitted markings at the base; they are from 2 to 3 cm. in length and from 12 to 42 microns in diameter; the cell-wall is from 1.4 to 4.2 microns in thickness. At the base the fiber is somewhat enlarged and flattened, though this formation is not so perceptible as in the case of *Beaumontia grandiflora*. The fiber of *Calotropis gigantea* (Fig. 266) is known in Venezuela as

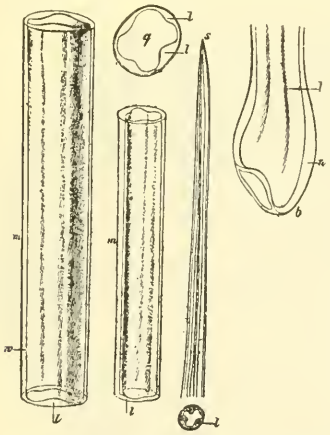


Fig. 265.—Structure of Vegetable Silk from *Beaumontia Grandiflora*: *b*, Root or base; *s*, point or end; *q*, cross-section; *m*, middle portion of fiber; *w*, cell-wall; *l*, cell-wall in section. (Höhnel.)

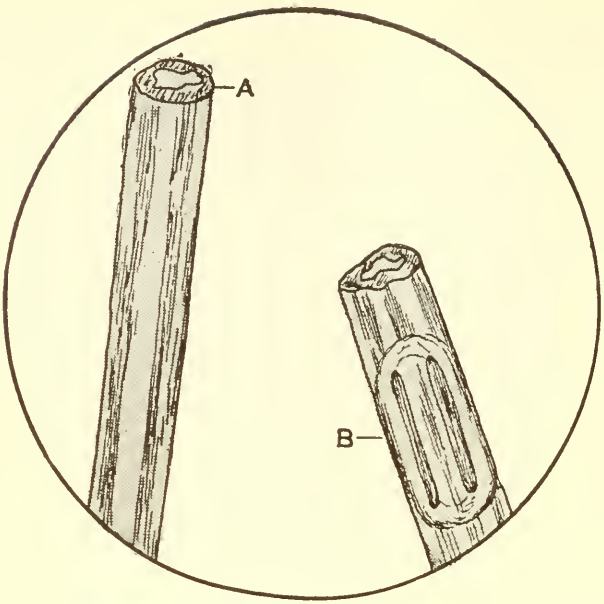


Fig. 266.—Vegetable Silk from *Calotropis gigantea*. Showing irregular thickening of cell-wall at *A*, and an air-bubble at *B*. Fibers examined in water. (Micrograph by author.)

algodon de seda. It is more yellow in color than asclepias cotton. The fibers from the various species of *Marsdenia* are very uniformly cylindrical and straight (Fig. 267). In length they vary from 1 to 2.5 cm. and in diameter from 19 to 33 microns. The cell-wall has an average thickness of 2.5 microns. The fiber of *Strophanthus* differs somewhat from other varieties, in that at the base there occur pores in the cell-walls. This fiber is also not so easily removed from the seeds and possesses a reddish yellow color.

The *Calotropis gigantea*, or giant asclepias, also yields a bast fiber said to be of very superior quality, somewhat resembling flax in appearance and of the same strength. The vegetable silk enveloping the seeds is known in India as madar floss. The bast fiber is said to show a high degree of resistance to moisture; according to Spon, samples exposed

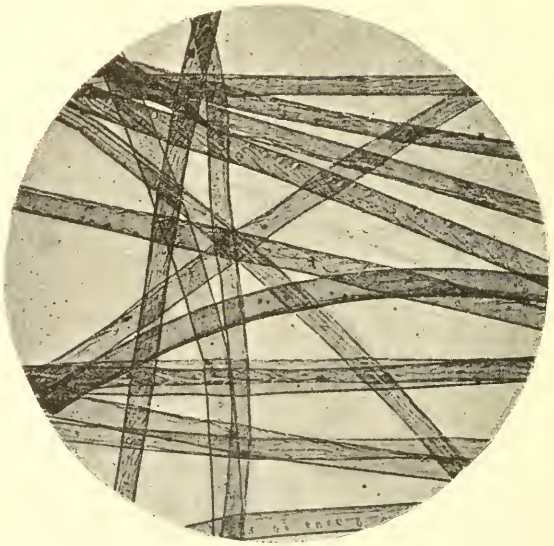


Fig. 267.—Fibers of Vegetable Silk from Marsdenia. (Herzog.)

for two hours to steam at two atmospheres pressure, boiled in water for three hours, and again steamed for four hours, lost only 5.47 percent in weight, whereas flax under the same conditions lost 3.50 percent, manila hemp 6.07 percent, hemp 6.18 to 8.44 percent, and coir 8.14 percent. As to the strength of the fiber, Dr. Wright's tests give it a breaking strain of 552 lbs. as compared with 404 lbs. for sunn hemp; Royle's tests give it a breaking strain of 190 lbs. as compared with 160 lbs. for Russian hemp and 190 lbs. for Jubbulpore hemp from *Crotalaria tenuifolia*.

The vegetable silk from *Calotropis gigantea* is sometimes known under the name of kapok, though this name is also given to the product of the *Eriodendron anfractuosum* and *Bombax pentandrum*. The fiber is said to have been made into shawls and handkerchiefs, but it hardly possesses sufficient strength to be spun alone. The *C. gigantea* is not only a fiber plant, as it also yields gutta-percha, varnish, dye, and medicinal substances.

The ridges in the fiber of *Calotropis gigantea* are evident in surface view only after a careful search, but in cross-section are more noticeable. Here and there air-bubbles are present in the lumen and may be recognised by their different refractive power. Often one of the ridges is more or less crooked. When treated with iodine-sulfuric acid reagent of suitable strength the hairs exhibit three layers: (1) A pale yellow slightly altered outer layer; (2) a greenish middle layer with swollen and constructed outer contour; and (3) a narrow inner tube.[1]

5. Vegetable wool is a product obtained from the green cones of the pine and fir by processes of fermentation, washing, and mechanical disintegration. It is used in mixtures with cotton and wool for the production of yarns, and also for the stuffing of mattresses, etc. The yarns prepared from vegetable wool mixed with sheep's wool are used in the manufacture of the so-called "hygienic flannels." These are especially recommended for gouty patients, as it is claimed they keep the body uniformly warm and protect it from dampness.

[1] Hanausek, *Microscopy of Technical Products*, p. 70.

CHAPTER XXI

ARTIFICIAL SILKS

1. Classification.—Owing to the high price and value of silk as a textile fiber, numerous attempts have been made to produce an artificial filament resembling it in properties. The entomologist Réaumur, in the year 1734, in a memoir on the history of insects, appears to have been the first to look forward to the possible preparation of silk by artificial means. It was not until 1884, however, that the first commercial process for the preparation of artificial silk was taken out in patent form by the Count Hilaire de Chardonnet.[1]

The first attempt at the spinning of a solution of collodion appears to have been made by Audemars at Lausanne.[2] Further experiments were made by Weston[3] and Swan[4] on solutions of nitrated cellulose in acetic acid. Wynne-Powell[5] tried the preparation of filaments from a solution of cellulose in zinc chloride. All of these attempts had in view the preparation of filaments for incandescent electric lamps.

The varieties of artificial silks divide themselves into the following classes:

(1) Pyroxylin or collodion silks, made from a solution of nitrated cellulose in a mixture of alcohol and ether.

(2) Cuprammonium or cuprate silks, made from a solution of cellulose in ammoniacal copper oxide.

(3) Viscose silks, made from a solution of cellulose thiocarbonate.

(4) Acetate silks, made from a solution of cellulose acetate.

(5) Gelatine silks, made from filaments of gelatine rendered insoluble by treatment with formaldehyde.[6]

[1] *Brit. Pat.* 6045 of 1885.

[2] *Brit. Pat.* 283 of 1855.

[3] *Brit. Pat.* of September 12, 1882.

[4] *Ger. Pat.* 30,291 of 1884.

[5] *Brit. Pat.* of December 22, 1884.

[6] *Artificial Silk from Milk.*—A recent British patent describes the following method for the manufacture of artificial silk. Milk is treated with sodium pyrophosphate in the proportion of 3 grams of the latter to 1 liter of milk. This mixture is allowed to stand for some time, when the casein separates as a jelly-like mass. The whey is run off and the casein is converted into a tough plastic mass by adding a small quantity of alkali. This is redissolved, the solution is filtered, and again precipitated by the addition of acid. The resulting product is pressed free from water, and then kneaded

With the exception of the last class, all of these so-called silks are filaments of cellulose, resolidified from various kinds of solutions, hence it has been proposed to give to these fibers the general name of **lustra-cellulose** as one more descriptive of their true nature.[1]

From the term "artificial silk," it might be reasonably supposed that the substance so designated is the same in composition and nature as the fiber derived from the silkworm, but made by chemical or other artificial means. This is not the case, however, and the term "artificial silk" is rather a misleading one in this sense. The name in reality stands for a fiber resembling in its luster and general appearance the true silk of nature; but the identity goes no further than this; for, in its chemical composition and properties, artificial silk is entirely distinct from that produced by the silkworm. It would be better to call the artificial product "imitation silk," or give it some name more distinctive of its origin and true nature, such as the term "lustra-cellulose," proposed by Cross and Bevan. The latter term is especially adapted to the product in question, for the different varieties of this fiber which have acquired any degree of technical importance are all made from cellulose derivatives, and their chief quality is their high degree of luster.

with a little ammonia. After standing for a time the mass becomes transparent and glossy, and can be drawn out into fine threads, which may be coagulated by treatment with formaldehyde.

A rather unusual variety of artificial silk is that described by L. Drut in *Fr. Pat.* 509,723. Air or gas bubbles are introduced into viscose solution, cellulosic cuproammoniacal solution, collodium, glue, cellulose-acetate, etc., in order to obtain a textile which, instead of being filled, is entirely or partially hollow. The emulsion thus formed is spun so that yarns are produced in which the cylinder is partially or entirely hollow.

[1] Of the several methods of making artificial silk, probably the most economical one is the viscose process. The collodion method at first enjoyed great success and factories working by this process in past years have made large profits; but owing to the high cost of the alcohol-ether solvent employed, it would not seem that this process could compete with the viscose method. The cuprammonium process also seems to be doomed, for though companies operating under this process have also made large profits, they have mostly taken up the viscose method. With the present high prices obtained for artificial silk, however, (1922) it is possible to manufacture the product by any one of these three processes at a good profit. Under conditions of rigorous competition, however, it would seem from an economic point of view that the viscose process would be the only one that stood a chance of permanently surviving, unless very radical improvements are made in the cost of manufacture under the other two methods. From data obtained in 1917 of the factory costs of the three varieties of artificial silk, the following figures were derived:

	Cost per Pound.
Viscose silk	$0.67
Cuprate silk	1.05
Chardonnet silk	1.31

It is highly probable that the same ratio of costs holds even at the present time.

The majority of the lustra-cellulose used in trade at the present time falls under the first three classes of silks. The pyroxylin silk represents the oldest method employed for the manufacture of this interesting fiber; and there are three chief processes by which this silk is made, known by the names of the respective inventors: Chardonnet, du Vivier, and Lehner. All of these processes use a solution of nitrated cellulose as a base, and employ the same general mechanical idea to produce the filaments of the fiber, the principle being to force a solution of nitrated cellulose through a fine capillary tube, coagulate the thin stream of solution thus obtained, and finally denitrate and reel the thread of filaments so obtained. As previously described, cellulose, on treatment with nitric acid, can be made to yield a series of nitrated celluloses, the exact compound obtained being dependent upon the conditions of treatment.

Artificial silk is chemically unlike natural silk and differs in most of its physical properties so that there has not been direct competition between the two fibers. The high luster of artificial silk, which is generally superior to that of the natural product, and its lower price have enabled it to fill a heretofore unoccupied place between mercerised cotton and natural silk. It is 10 to 20 percent heavier than natural silk, has from one-third to one-half its elasticity, and from one-half to two-thirds its breaking strength.[1] While natural silk is practically unaltered by contact with water, artificial silk swells rapidly and loses about 60 percent of its strength, so that it must be handled with care. However, by combination with other textile fibers in making fabrics subject to wetting, this weakness is overcome to a great extent. There has been difficulty in obtaining uniform results in dyeing artificial silk, which has served to restrict its use for some purposes.

The field of usefulness of artificial silk is restricted only by the physical limitations of the fiber. Originally inflammable, weak, and liable to severe injury by water, it was at first used only in the manufacture of braids and millinery and dress trimmings, for which it has now practically

[1] Rosenzweig (*American Silk Journal*) makes some interesting statements concerning artificial silk and its relation to natural silk. Artificial silk is the only thread made by man that is really "spun," for "spinning" is derived from the German "spinnen," the work of the "spinne" (spider), which forms a practically endless thread. All other threads are not really "spun," but "thrown," that is, formed by the method of twisting short fibers round each other. Therefore, real silk and artificial silk are the only "one piece" threads in the world, while all the others consist of little pieces twisted together. The brilliancy and smoothness of artificial silk is even superior to the real silk; it is, in fact, too smooth and brilliant. Its great smoothness is positively a drawback, as this will always remain a hindrance to forming a well closed fabric. In another respect, however, the smoothness is an advantage, as the material does not easily retain dirt and is easily cleaned. The space taken by 85 ozs. of real silk requires 100 ozs. of artificial silk to fill; this means that the latter is 20 percent less in covering power, and in comparative price, artificial silk at $2.80 would mean $3.35 as compared with real silk.

superseded natural silk. As now manufactured, artificial silk is no more inflammable than cotton and some varieties are entirely fire-resistant. It is strong enough to be handled by textile machinery either as warp or filling or both, and much progress has been made in making it resistant to water. In this country the hosiery industry is the largest consumer, while in the last few years the production of sweaters and other knitted goods has been important. Artificial silk is woven with natural silk, cotton or other fiber into dress goods, such as satins and fancy silks, and shirtings and tapestry. Plushes, carpets, and imitation furs are now made of artificial silk, and many kinds of fringes, tassels, and novelties. It is of value in the manufacture of gas mantles, elastics, shoe laces, and other articles of minor importance, and during the War it was used to a limited extent to make powder bags and parts of gas masks.

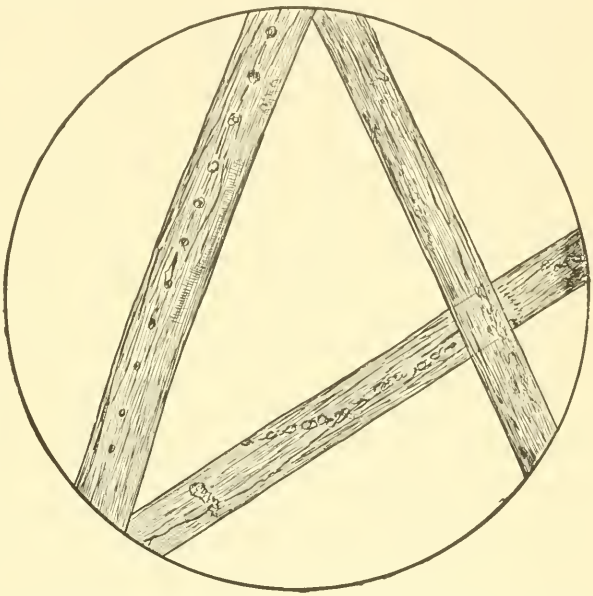


Fig. 268.—Chardonnet or Collodion Silk. (×350.) (Micrograph by author.)

2. Collodion or Chardonnet Silk.—This is prepared from nitrated cellulose dissolved under pressure in a mixture of alcohol and ether. The solution is coagulated by passage through water, and is subsequently denitrated by a treatment with dilute nitric acid, chloride of iron, and ammonium phosphate. It forms a glossy, flexible fiber, possessing the peculiar feel and scroop of true silk.

Many attempts have been made to reduce the cost of the collodion and to obtain other solvents for the nitrated cellulose. Bronnert in 1895 brought forward a process of making collodion, based on the solubility of tetranitrated cellulose in alcoholic solutions of certain salts, such as calcium chloride, ammonium acetate, and ammonium sulfocyanide. The explanations advanced for these reactions are rather uncertain. It may be supposed that the ammonium acetate produces a hydrolysis, the ammonium sulfocyanide a partial denitration of the tetranitrated cellulose,

and the calcium chloride an alcoholic derivative of the cellulose, which could well be an ethoxy-derivative, if the opinion of Dr. Bronnert, " that the body designated by the name of tetranitrated cellulose is a tetranitrated oxycellulose," is correct. The different compounds thus formed would be soluble in alcohol.[1]

When first prepared, pyroxylin silks were very inflammable, which led to their being regarded with disfavor. The processes of denitration, however, have now rendered them even less inflammable than ordinary cotton.[2]

The pyroxylin employed for the production of Chardonnet's silk may be prepared from either wood-pulp, cotton, ramie, or other source of purified cellulose. The nitrocellulose prepared from wood-pulp (sulfite) gives a more fluid solution when dissolved in the alcohol-ether solvent, but the fiber obtained after spinning is inferior in tensile strength, and is said to have less luster and purity of color than filaments produced from cotton as the source of cellulose. As there are several nitrated compounds of cellulose soluble in the alcohol-ether mixture (which is employed as the pyroxylin solvent), and as it is difficult to obtain satisfactory separations of the individual compounds, it is probable that the pyroxylin contains penta-, tetra-, tri-, and di-nitrated cellulose, the tetra- and tri-nitrated compounds probably occurring in larger amounts. The preparation of a pyroxylin, suitable for use in the making of Chardonnet silk, as prescribed by Wyss-Naef, calls for a nitrating mixture of 15 parts of fuming nitric acid (sp. gr. 1.52), with 85 parts of commercial sulfuric acid. For 4 kilograms of cellulose about 35 liters of this acid mixture are required, and the time of action is from four to six hours. Samples are examined from time to time, with the micro-polariscope in order to ascertain the degree of nitration, and when all the fibers appear of a uniform bright blue color under the polariscope the action of the acid mixture is discontinued. The excess of acid is removed from the fiber by means of a hydraulic press, after which the nitrated cellulose is washed for several hours with water and then pressed again, until the mass contains only about 30 percent of water. At first the pyroxylin so prepared was dried before being dissolved in the alcohol-ether solvent, but it was subsequently discovered that a better solution could be obtained by using the pyroxylin containing the amount of water above noted. This form of pyroxylin has been called by Chardonnet " pyroxylin hydrate," but it is doubtful if the substance is a true hydrate. However, it appears to be about 25 percent

[1] See Bernard, *Mon. Scientif.*, May, 1905.

[2] *Antiphlogin* is the trade-name of a mixture used for the purpose of overcoming the inflammable nature of artificial silk. It consists of boric acid, phosphate of ammonia, and acetic acid. Pyroxylin steeped in this solution is said to be incombustible.

more soluble than the dry pyroxylin. The solvent employed for the pyroxylin formerly consisted of a mixture of 40 parts of 95 percent alcohol [1] with 60 parts of ether, and 100 parts of this liquid would dissolve about 28 to 30 parts of pyroxylin. The collodion so produced is filtered several times under pressure, in order to free it from all non-nitrated and undissolved fibers, and to obtain a perfectly clear and homogeneous solution. This condition is a very essential one for the successful production of the silk, as any irregularity in the solution would cause a break in the continuity of the spun filament or a stoppage of the machine. The pyroxylin requires from fifteen to twenty hours for complete solution, and that prepared from cotton requires a longer time to dissolve than that from wood-pulp. In order to properly filter the solution a pressure of 30 to 60 atmospheres is necessary. A rather recent improvement in the making of collodion silk is to dispense with the ether in the solvent, using a mixture of alcohol and calcium chloride to dissolve the di-nitrocellulose (Bronnert). This is far more economical and reduces the fire and explosive risks.

The next operation in the manufacture of the silk is purely a mechanical one, and yet one which has required the use of considerable ingenuity and skill. The object is to force the collodion solution through very fine capillary glass tubes, so that it may be drawn thence as a fine continuous filament. The collodion solution is quite viscous, and requires a pressure of from 40 to 50 atmospheres to force it through capillaries of 0.08 mm. diameter. As the solutions of nitrated cellulose possess great viscosity, it is difficult to prepare a very concentrated solution. The addition of formaldehyde or benzene, however, to the ordinary solvents, will increase the dissolving capacity considerably, and also give a more mobile solution. Epichlor- and dichlorhydrins also act as excellent solvents for nitrated cellulose, being capable of dissolving it in any proportion.

The flow of solution and pressure must be so adjusted and capable of regulation as to provide a uniform filament, and this involved many mechanical difficulties, which were only overcome after long experimenting and numerous failures. We will not, however, at this point enter into a consideration of the various mechanical devices, ingenious though they are, which have been perfected for the proper spinning and handling of this artificial fiber.[2]

An outline of the methods employed in the practical manufacture of Chardonnet silk is as follows: A good quality of wood-pulp is carefully disintegrated by suitable machines (resembling a carding-machine), so

[1] At the Besançon works, 1 kilo. of finished silk requires 4–5 liters of alcohol in its manufacture.

[2] See Süvern, *Die kunstliche Seide*, Berlin, 1912, and Williams, *La Soie Artificielle*, Paris, 1902.

as to separate the individual fibers as much as possible. The purity of the original cellulose, which may be either cotton or bleached sulfite wood-pulp, is as important as its physical condition before conversion into the ester. Previous mercerisation or subsequent hydration of a cellulose before esterifying is found to influence greatly the viscosity of the resulting solutions. This viscosity is one of the most important factors in the spinning process itself and greatly influences the quality of the thread which is produced. The bulky, fleece-like mass is then dried by steam heat at 140°–160° C., after which the heated fibers are steeped in a mixture of concentrated sulfuric and nitric acids, as in the general method of making guncotton. The temperature at which the cellulose is converted into the ester is of great importance, for it must be remembered that cellulose is by no means as chemically indifferent as is generally supposed. Cellulose, in fact, is rather easily degraded by chemical treatment, especially at elevated temperatures; the original molecular weight is lowered and there is loss of chemical and physical resistance. After suitable treatment in the acids, the nitrated cotton is centrifuged to remove excess of acid, then washed until it contains only about 10 percent of acid. The product was formerly dried in special drying-rooms, where the temperature should not be above 30° C., and every precaution must be taken to avoid explosions. The dried nitrated cellulose was then dissolved in a mixture of equal parts of alcohol and ether, so as to secure a 20 percent solution. The resulting collodion (as the solution is now known) is carefully filtered through silk sieves in such a manner as to remove all undissolved fibers or other foreign matter. The collodion then passes to the spinning-machine where it is forced through tubes having nozzles of glass or platinum with fine orifices. As the threads of collodion

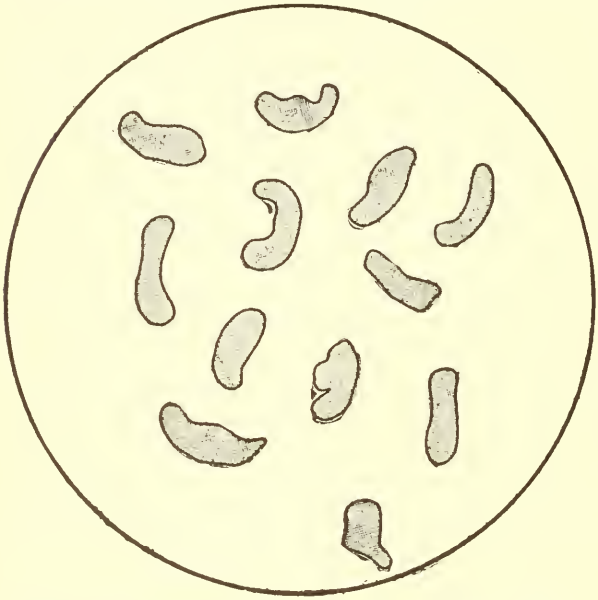


Fig. 269.—Cross-sections of Collodion Silk. (×250.)
(Micrograph by author.)

appear they come into immediate contact with a fine stream of water, which removes the solvent and coagulates the cellulose compound. Recently, however, methods have been devised to spin the filaments dry instead of under water. Several of the fine threads are united and are wound on bobbins and into suitable hanks. The silk is then denitrated by treatment with a warm solution (5 to 20 percent) of ammonium sulfide, after which the hanks are washed and slightly acidified in order to remove all the ammonium compounds. The process of denitration causes the silk to lose about 40 percent in weight, though this is usually replaced in part by proper impregnation with solutions of metallic salts, which also have the effect of making the silk fireproof. In the manufacture of collodion silk, an important factor is the recovery of the solvent from the wash-waters; owing to the extreme volatility of the ether this is by no means an easy task.

One of the most characteristic features of the Chardonnet process is the use of very highly concentrated solutions of nitrocellulose in order to economise alcohol and ether. The solution can be drawn out into threads directly into hot air, especially if wet and hydrated nitrocellulose has been used. The air is then freed from water by cooling, and the vapors of alcohol and ether are condensed by pressure or other suitable methods. The high pressure necessary for forcing the highly concentrated and very viscous solutions through the extremely fine apertures of the spinnerets makes the spinning a tedious process and often results in irregularities in the thickness of the filaments. Chardonnet works with collodions containing from 20 to 25 percent of nitrocellulose and forces them through apertures of a diameter of 0.08 to 0.05 mm. The finest miller's gauze of natural silk must be used for filtering these solutions to prevent rapid choking of the spinnerets. Lehner tried using coarser apertures of about 0.2 mm. and his solutions contained only about 8 percent of nitrocellulose. In this way he overcame the difficulties due to high pressure, but, on the other hand, it was no longer possible to spin in hot air and the thread was spun into water which absorbed the alcohol and some of the ether. Bronnert later improved the method by omitting the ether from the solvent mixture, as he found that di-nitrocellulose could be dissolved in alcohol containing a certain amount of chloride of calcium. The resulting collodion was not explosive and the alcohol could be almost entirely recovered by spinning the thread into warm water.

The thread as it emerges from the capillary tube is rapidly coagulated in the air by the evaporation of the solvent. By suitable arrangement of a hood over the machine and condensing chambers in connection therewith, a large portion of the mixed volatile vapors of the alcohol and ether employed as the solvent are condensed and collected, thus effecting a considerable saving in the amount of solvent required, and also mini-

mising the danger of explosions occurring. Several of the individual filaments are brought together into a single thread and wound on spools in the manner of ordinary silk. In this operation a certain amount of adhesion takes place between the separate filaments, which considerably enhances the ultimate strength of the finished thread. The thread in this form now consists of pyroxylin or nitrated cellulose, and is highly inflammable and otherwise unsuitable for use in textiles.

The next operation through which it passes is one for the purpose of denitrating the cellulose, in order that the fiber may ultimately consist of what might be termed "regenerated" cellulose, the exact chemical nature of which it is not possible to state definitely, though it is evidently some form of cellulose. The denitration is accomplished by passing the pyroxylin threads through a bath of ammonium sulfide, though other alkaline sulfides, and various other compounds also, will effect the same result. The silk in this condition has a rather yellow color, which, however, may be bleached out in the usual manner with a solution of chloride of lime or sodium hypochlorite. The fiber, as finally obtained, possesses a very high luster, though it is somewhat metallic in appearance; it has considerable tensile strength, though in this respect, as also in elasticity, it is considerably below true silk. The fiber is also rather harsh and brittle, and does not possess the softness and resiliency of natural silk.[1]

Many improvements have been made in the matter of preparing the solution of pyroxylin for artificial silk. Bronnert [2] discovered that by using calcium chloride with alcohol the nitrocellulose could be dissolved without the use of ether. Various other organic and inorganic salts also have the effect, but the calcium chloride collodion has been the most practical and has been used for a long time, thus getting rid of the troublesome and expensive ether. The calcium chloride appears to bring about a condensation product of the nitrocellulose with the alcohol. Although solution is instantaneous when a molecule of calcium chloride is added to a molecule of tetra-nitrocellulose, the maximum liquefaction is reached in about half an hour, when the mixture is heated to 60° or 70° C. and the vapor then cooled. The fluidity of the solution can also be increased by nearly 30 percent if, before nitration, the cellulose be submitted to an energetic hydration by mercerising it, for example, with caustic soda, and then washing it well with water. The nitration of cellulose can conveniently be followed by a slight bleaching with lime; the esterification of the four hydroxyl groups (OH) seems to protect the molecule from subsequent oxidation. Chardonnet has shown that if the cellulose is bleached with chlorine and then nitrated, the collodion, manufactured from the

[1] See Matthews, *Jour. Soc. Chem. Ind.*, 1904, p. 176.

[2] See *Brit. Pat.* 1858 of 1896.

nitrocellulose thus formed, does not spin so well as if the treatment with chlorine had been omitted.

According to Dulitz [1] it is not possible to obtain a product absolutely free from all traces of nitrogen without the destruction of the filament. For practical purposes the denitrated silk contains about 0.05 percent of nitrogen. The uniformity of denitration is very important, and is one of the chief difficulties in the manufacture of collodion silk. According to Gorrand,[2] the addition of a small quantity of acetic acid to the collodion solution before spinning accelerates the subsequent denitration process with ammonium sulfide. Pyroxylin silk loses about 8 percent in strength by denitration. It is probable that some oxycellulose is formed in this process.

For the bleaching of Chardonnet silk the proportions are as follows:

	Pounds.
Artificial silk	16
Bleaching powder	4
Hydrochloric acid	8

The bleached skeins are washed in cold water to remove all trace of chlorine, then softened with Turkey-red oil.

Dulitz [3] states that in the bleaching of collodion silk the use of bleaching powder is now almost entirely discarded since it injuriously affects the strength of the fiber and causes subsequent discoloration. Various peroxides and per-salts have been tried but owing to their high cost, and to the fact that they tend to produce a harsh fiber have not been generally adopted. Sodium hypochlorite solutions having a concentration of 0.5 gram of active chlorine per liter are now in general use, often with the addition of sodium carbonate or Turkey-red oil. Hydrochloric acid is mostly used for souring as it is most easily removed by washing and gives a softer thread. Treatment with soap or Turkey-red oil, without washing, before immersing in the bleach liquor is said to be advantageous.

In the collodion process there are certain defects readily appreciated by chemists, especially the presence of sulfuric acid groups in the product not entirely removed in the denitration treatment. This treatment is not a simple saponification of the nitrate, and it does not appear to be possible to effect this simple reversal in the case of the nitrates of cellulose. The treatment with alkali for such purpose causes a destructive action on the cellulose complex. The process devised to avoid this is one based on the de-oxidation of the acid residues and combination with bases to soluble forms.

[1] *Chem. Zeit.*, 1910, p. 989.
[2] *Fr. Pat.* 354,424 of 1905.
[3] *Chem. Zeit.*, 1911, p. 189.

According to Foltzer [1] in the modern process for preparing Chardonnet artificial silk the washed cotton is converted into nitrocellulose by immersing 4 kilos. (8.816 lbs.) of cotton in 35 liters (7.7 gallons) of a mixture of nitric acid and sulfuric acid; the proportions being 15 percent of nitric acid, specific gravity 1.52, and 85 percent of ordinary sulfuric acid. The cotton remains in the mixture from four to six hours, and the degree of nitration depends upon the time of immersion. This degree of nitration can only be determined with a microscope and by the aid of polarised light. The acid is afterward pressed out of the nitrocellulose, and the latter is then washed until no trace of acid remains. Finally, the water is removed from the substance by means of hydraulic presses or hydro-extractors until there remains not more than 36 percent of water. In this state the nitrocellulose is inflammable only to a slight degree, a condition which is of great importance for its ultimate use. To 22 kilos. (48.5 lbs.) of this nitrocellulose are added 100 liters (22 gallons) of a mixture of equal quantities of ether and alcohol. This solution is then filtered and kept in large reservoirs. Experience has shown that a solution which has been kept for several days will produce a better quality of silk than a freshly prepared solution. From this pulp the silk is afterward spun. For this purpose a very simple apparatus is used, consisting of a certain number of glass tubes, each drawn out to a capillary tube or spinneret with a bore varying from 0.1 mm. to 0.2 mm. The nitrocellulose is forced through these capillary tubes under a pressure of 60 kilos. per square centimeter (853 lbs. per square inch). Several of these threads are grouped together as they pass through a guide to be wound untwisted on to a bobbin; the group corresponding in count to one thread of natural silk. On drying, these threads acquire a certain degree of luster, strength, and elasticity. The threads are dried in a stove which is heated to 45° C. (113° F.), and which is well ventilated. In this manner the alcohol and the ether still present in the silk are volatilised, and, in consequence, the degree of inflammability of the thread is lowered considerably. However, in order to render the thread absolutely non-inflammable, it should be denitrated—an operation which is carried out in a bath of alkaline sulfides. Thus a thread is produced which possesses strength and elasticity; its color is inclined to yellow, but the thread may afterward be bleached with chloride of lime.

The denitration of the nitrated cellulose, previously made up in the form of hanks, is always carried out in a solution of alkaline hydrosulfides. At Besançon, calcium hydrosulfide was employed. With calcium hydrosulfide the thread becomes hard and brittle; its strength and its elasticity diminish greatly. Ammonium hydrosulfide denitrates successfully under the influence of heat, but care must be exercised in its use, and its applica-

[1] *Textile Manufacturer.*

tion is expensive. Another disadvantage is its odor, which is very disagreeable, although it is less dangerous to health than that of concentrated sulfuric acid. Magnesium hydrosulfide has the advantage of being cheaper; it denitrates much more quickly, and it yields a stronger thread. A mixture of ammonium hydrosulfide and a salt of magnesium is more stable than pure ammonium hydrosulfide, and it does equally well for the purposes of denitration; its use, however, involves unnecessary expense.

By exercising certain precautions it is possible to denitrate with sodium hydrosulfide. In general it is best to denitrate at a low temperature. This precaution prevents the sulfur—which at the moment of reaction is liberated by the oxidation of hydrogen sulfide in presence of nitric acid—from being deposited on the fiber. For each hydrosulfide there is a limiting low temperature at which the denitration is rapidly performed; while at a still lower temperature the denitration is incomplete and proceeds slowly.

In practice it is unnecessary that the saponification of the cellulose ester of nitric acid should be accompanied by a complete reduction of the nitric acid produced. For complete reduction eight molecules of hydrogen sulfide would be required for one molecule of tetra-nitrocellulose. By taking certain precautions, however, the denitration may be carried out with four molecules of hydrogen sulfide. The greater part of the nitric acid thus formed is reduced, and the resulting nitrous acid unites immediately with one of the bases present. Very little ammonia is formed. Ammonium sulfide produces, in small quantities, oxysulfide, sulfites, and thiosulfates, which cause the sulfur to remain in solution in the form of polysulfides. In this manner the luster of the fiber is not altered in the slightest by the presence of sulfur. The threads of the denitrated cellulose contain only traces of nitric groups. These groups are sufficient, however, for the identification, by means of diphenylamine, of artificial silks derived from cellulose by this process.

3. Lehner's Silk.—A development of collodion silk of secondary importance was associated with the name and work of Lehner, who elaborated a simplified method spinning or drawing the collodion solution to a thread. The Chardonnet process of forming the solidified thread of cellulose nitrate by evaporation of the volatile solvents was replaced by the method of precipitation or coagulation by the action of water as a spinning bath, which thus took up the alcohol and, in part, the ether of the solution, to be afterward recovered by evaporation. Both Lehner and du Vivier appear to have exercised ingenuity in the unpromising field of compound colloids as the basis of a textile thread, using mixtures of nitrocellulose with protein colloids, oxidised derivatives of drying oils, and the like. The Lehner process was demonstrated at Bradford, and according to C. F. Cross, was found wanting in commercial success as compared with the

simple and specific variants of the Chardonnet technique, which had already been set forth in his earlier communications. While with Chardonnet the concentration of the collodion was as high as 20 percent Lehner used only 10 percent solutions. The pressure required for spinning was also considerably reduced by lowering the viscosity of the solution by the addition of a small amount of sulfuric acid. Lehner also attempted the use of natural silk waste dissolved in glacial acetic acid.

Lehner equipped a factory in Switzerland, but did not succeed in producing a saleable thread until he abandoned the use of all his patented modifications, and now manufactures by much the same means as that of Chardonnet, and the fiber is very similar to that of the latter. Lehner at first attempted to obtain a fiber from a mixture of pyroxylin solution with various vegetable gums and oils, with solutions of cotton in copper-ammonium sulfate, and even with solutions of waste silk, itself. None of these, however, proved a success, and he reverted to the more simple solution of pyroxylin in combination with a drying oil. He also discovered that the fluidity of the collodion could be materially enhanced by the addition of sulfuric acid, and consequently he was able to work his solution under much less pressure than Chardonnet.

4. Other Collodion Silks.—There have been a variety of modifications in Chardonnet's method for the preparation of the collodion solution and the details of spinning the filament. Du Vivier's silk, known also as "*Soie de France*," was prepared from a solution of nitrated cellulose in glacial acetic acid to which gelatine was added. Substances such as a solution of gutta percha in carbon disulfide, glycerol, and castor oil were also added. A coagulating bath of sodium bisulfite was employed and the silk was subsequently denitrated in the form of hanks. Du Vivier's silk, however, did not pass beyond the experimental stage, and is no longer on the market.

Crespin [1] has endeavored to minimise the amount of solvent by dissolving the nitrated cellulose in a mixture of methyl and ethyl alcohols and ether, to which solution is also added some glycerol and castor oil. Cazeneuve [2] has claimed the use of acetone as a solvent for the nitrated cellulose; but a filament spun from an acetone solution is opaque and brittle. The suggested improvements and modification of processes for the preparation of collodion silk have been legion, as evidenced by the large number of patents taken out in this field; most of these, however, are worthless or impracticable.[3]

Chardonnet was obliged to use high pressures (60 kilos. per square

[1] *U. S. Pat.* 820,351 of 1906.

[2] *Fr. Pat.* 346,693 of 1904.

[3] For a complete presentation of this patent literature consult Süvern, *Die kunstliche Seide*, 1920. Also see Worden, *Nitrocellulose Industry*, 1911, pp. 454–565.

centimeter and more, 853 lbs. per square inch) in order to be able to force his highly concentrated solutions through the openings of the capillary tubes. This pressure increases as the fluidity of the collodion diminishes, and the fluidity diminishes greatly for a slight increase in the concentration of the collodion.

Lehner noted that concentrated sulfuric acid and hydrochloric acid exercise a liquefying action on the collodion. Chardonnet observed that the addition to the collodion of aldehyde, ethyl-sulfuric acid, and ammonium chloride, also produced liquefaction. Bronnert noted that alcoholic solutions of certain substances, whether organic or inorganic, dissolve nitrocellulose easily, whereas alcohol alone does not. The degree of solubility, as well as the properties of the solution, varies according to the substances employed. Besides the calcium chloride method already mentioned, Bronnert observed that alcoholic solutions of ammonium acetate also dissolve nitrocellulose very readily; but the solutions obtained by this means have not the necessary viscosity for satisfactory spinning. When these solutions are raised to a high temperature in a vapor bath they become brown and acquire a degree of fluidity which renders them useless for the operation of spinning into thread. If they are evaporated on a glass plate, the residue possesses neither coherency nor elasticity, but crumbles on being touched.

Ammonium sulfocyanate dissolved in alcohol has also the property of dissolving nitrocellulose; but if this dissolved substance is allowed to remain for several weeks it turns into a gelatinous material of a yellowish color.

Besides the processes previously given of obtaining collodion silk, there are other methods for the manufacture of this artificial product. Langhaus employs as a raw material a preparation from cellulose and sulfuric acid. This process consists in dissolving cellulose in a mixture of concentrated sulfuric acid and phosphoric acid, and treating the syrup so obtained with glyceric ether or ethyl ether. The silk obtained by this process is not of good quality, and the solution is not very stable, as it soon precipitates more or less altered cellulose. Cadarat uses nitrated cellulose, dissolving it in a very complex mixture of glacial acetic acid, ether, acetone, alcohol, toluol, camphor, and castor-oil. This forms a plastic mass which is treated with some proteid substance, such as gelatine or albumen dissolved in glacial acetic acid. After spinning the fibers are treated with tannin in order to render them elastic.

5. Cuprate or Cuprammonium Silk.—Lustra-cellulose threads are also prepared from a solution of cellulose in ammoniacal copper oxide solution (Schweitzer's reagent). Weston, in 1884, used this solution for the making of incandescent-lamp filaments; Despeissis, in 1890, first thought of applying it to the preparation of artificial silks. Frémery and Urban, in 1897,

under the name of Pauly, patented the first practical process for the manufacture of the fiber.[1] This silk is now made in considerable quantity by several factories in Europe and America. The product is known as *Glanzstoff, Tubize, Cuprate, Pauly's silk* or *Parisian artificial silk.*

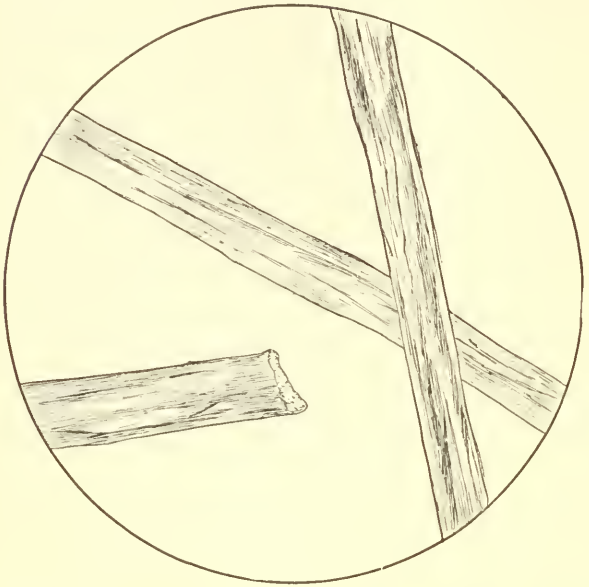


Fig. 270.—Cuprate or Glanzstoff Silk. (×350.) (Micrograph by author.)

Pauly's process in brief was as follows: The copper solution is first prepared by treating copper turnings with ammonia in the presence of lactic acid at a temperature of 4° to 6° C. At the end of about ten days the intense blue solution of ammoniacal copper oxide is ready for use. The next step is to obtain mercerised cellulose (cellulose hydrate),[2] which is done by mixing 100 parts of cotton with 1000 parts of a solution containing 30 parts of sodium carbonate and 50 parts of caustic soda.

[1] *Brit. Pat.* 28,631 of 1897.

[2] Foltzer (*Textile Manufacturer*) states that in order to reduce the net cost, the Elberfeld factory used the wood of bamboo canes as raw material. The resulting threads were, however, very much inferior to those obtained from cotton cellulose. Bamboo plants, as well as other plants of the same class, contain a large quantity of pecto-celluloses, with a greater or less proportion of lignocelluloses; the structure of these non-cellulosic bodies is little known. Later, the above firm tried solutions made from paper, but finally returned to cotton cellulose. The grading of cotton is done by hand, and those who have had considerable experience can judge, by handling the material, of its fineness, length, strength, and the degree to which it may be drawn. In the manufacture of artificial silk, however, the difference in the prices of the raw materials is of less importance at the present time than the maintaining and keeping in good repair of the very costly capillary tubes, glass bobbins, etc., and, in general, the mechanism of the works. The manufacturers of artificial silk buy, in general, cotton ready prepared for solution, and they demand from the bleacher guaranteed limits of moisture, ash and grease. The moisture must not exceed 6 percent, and the grease and ash combined not more than 0.4 percent. It is also wise to ascertain the quantity of chloride of lime which has been employed for the bleaching process. This quantity is, in general, 5 lbs. for 100 lbs. of cotton.

This mixture is heated for $3\frac{1}{2}$ hours in a closed vessel under a pressure of $2\frac{1}{2}$ atmospheres. The mercerised cotton thus obtained is washed, dried, bleached with chloride of lime, washed and again dried; after which it is dissolved in the ammoniacal copper oxide solution. The solution (containing 7 to 8 percent of mercerised cotton) is filtered, settled, and then spun through capillary tubes under a pressure of 2 to 4 atmospheres. The thread is coagulated by passing through a bath of acetic acid or one containing 30 to 65 percent of sulfuric acid, at the ordinary temperature.

Ordinary cellulose dissolves but very slowly in Schweitzer's reagent, and moreover, the solution is always accompanied by oxidation which changes the cellulose molecule so that it is not fit to spin. Bronnert first proposed the use of cellulose hydrate, and so made the method of practical value.

Friederich prepares stable solutions of cuprammonium cellulose by dissolving 4 kilos. of copper sulfate, $CuSO_4$, in $1\frac{1}{2}$ liters of water, and adding 2.41 liters of caustic soda of 38° Bé. and 1 liter of water. He then adds 20 grams of dextrin, which are taken up by the hydrate of copper which is formed, and 200 grams of cut-up cotton fiber. The insoluble cellulose pulp impregnated with the hydrate of copper is separated by the aid of a filter-press, and is mixed with 1 liter of concentrated ammonia. In a short time there is produced a homogeneous solution containing 8 to 9 percent of cellulose which is very stable owing to the presence of dextrin. Mannite, glycerol, and crude cane molasses may also be used in place of the dextrin. This solution may be heated to 30° to 40° C. without danger of decomposition.[1] Pawlikowski prepares cuprammonium solutions of cellulose[2] by the aid of copper oxychloride, which renders unnecessary the previous hydration of the cotton with caustic soda, that is to say, mercerising and bleaching. The following proportions are recommended for use:

100 grams of pure cotton linters;
90 " copper oxychloride (containing 44 to 57 percent of copper);
900 cc. of ammonia water (0.93).

Foltzer (*Textile Manufacturer*) gives the following notes concerning the preparation of the cuprammonium solution of cellulose: When ordinary cotton is brought into contact with Schweitzer's reagent, it swells and dissolves only so far as the solvent acts chemically on the cotton fiber. If this operation is carried out at the ordinary temperature, the cellulose is peroxidised, and the solution can no longer be used for the manufacture of artificial silk. If, on the contrary, the solution is effected at a low temperature, and if the copper and the cellulose are used in certain pro-

[1] *Fr. Pat.* 404,372; also 418,182 and 405,571.
[2] See *Fr. Pat.* 403,448.

portions, the threads obtained possess the necessary physical properties. But this solution takes place only slowly; in order, therefore, to avoid this loss of time, the cellulose is prepared by preliminary processes, and in such a way that a relatively short time only is necessary for the operation. By a prolonged oxidation of the cellulose with a clear solution of chloride of lime, a product is obtained which dissolves easily up to 8 percent in a solution of ammoniacal copper oxide. The thread made from this solution is easily dyed with basic coloring matters, and behaves in this case as an oxycellulose. In order to be more sure of obtaining a good result, the solutions are made from cellulose which has been previously hydrated. This is done simply by treating the cellulose with cold concentrated caustic soda, and afterwards washing the soda cellulose in pure water. Cellulose thus prepared dissolves almost immediately in ammoniacal copper oxide solution kept at a low temperature. It is customary to add to these solutions a little antimony and tannin; these astringent substances are by no means injurious to the luster of the thread. The process of solution can be simplified further by treating, at a low temperature, hydrated cellulose with a concentrated solution of caustic soda; the sodic cellulose thus obtained is then treated in the cold with a calculated quantity of a salt of copper, and the mixture is dissolved directly in ammonia. Whilst the hydrated cellulose is nearly insoluble in ammoniacal copper oxide solution, it dissolves with extraordinary ease in the same liquid if it has been previously hydrated by being treated first with a concentrated solution of caustic soda and afterwards with water.

Friederich [1] has suggested the use of alkylamines to replace the ammonia in the preparation of the copper-cellulose solutions.

The passage of an electric current through the liquid, or the presence of an electronegative metal in contact with the copper, is said to facilitate the solution of the cellulose. The operation is carried out cold, and is hastened by the presence of an excess of free copper hydrate or carbonate. The addition of caustic soda to the ammoniacal solution of copper is also said to facilitate the preparation of more concentrated solutions of cellulose, probably owing to the simultaneous hydration of the fiber. The cuprammonium solution of cellulose may be concentrated by evaporating from it a large part of the ammonia by a current of air. In this manner a solution may be obtained containing 10 percent of cellulose.

The cuprammonium filament may also be coagulated by passing through a 40 percent solution of caustic soda. The coagulated thread is washed with water, and the copper removed by treatment with an acid bath combined with the action of an electric current.

Berl [2] has investigated the formation and properties of cuprammonium solutions of cellulose. The viscosity of the solution depends on the

[1] *Fr. Pat.* 357,171. [2] *Chem. Zeit.*, 1910, p. 532.

previous preparation of the cellulose, the amount dissolved, and the age of the solution. The solution will rapidly absorb oxygen, leading to the formation of oxycellulose, which has little value for spinning. The formation of cuprammonium cellulose is said to be a colloidal phenomenon, the colloidal portion of the cuprammonium hydrate joining the cellulose to form an adsorption product soluble in ammonia. Bronnert [1] notes that hydrocellulose is practically insoluble in the cuprammonium liquor.

According to Foltzer (*Textile Manufacturer*), the apparatus employed for the making of the cuprammonium solution consists of a vertical cylinder (see *A*, Fig. 271). Small pieces of pure copper are introduced through an opening (*B*) into the cylinder (*A*). The empty spaces between the heaped-up particles of copper are filled with ammonia, which enters by the pipe (*C*). When the cylinder is full the opening is closed, and an air pump working at a pressure of about two atmospheres agitates the solution by internal circulation. In order to have control over the action, it is best to provide each cylinder with a meter or with a mercurial gauge, so that the quantity of air passed through in a given time may be noted. By Wright's method the speed of the air is regulated in such a manner that in one hour about forty times the liquid volume is allowed to pass through the column. The solution remains in the cylinder until it reaches the desired strength, which is measured by a hydrometer. To this end a gauge is provided through which a few centimeters of copper solution in ammonia are allowed to pass. When the liquid has attained the required degree of concentration, it is allowed to pass through the opening (*D*) into a graduated tank, the exact capacity of which is known. During the time that the copper oxide is dissolving in the ammonia, the temperature in the cylinder must be between 4° and 6° C. This temperature is regulated by means of a thermometer, which is fixed in the cylinder and dips into the solution. In order to maintain this approximately constant temperature, the cylinder is surrounded by a double cover which is protected by insulating materials.

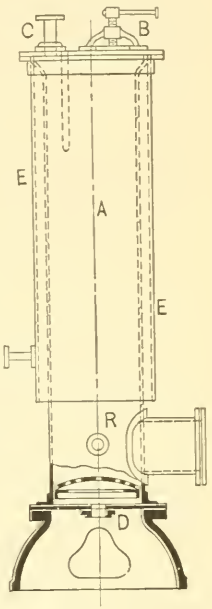


FIG. 271.—Apparatus for Preparing Cuprammonium Solution. (Foltzer.)

The ammoniacal solution of copper oxide is prepared very gradually, and in order to arrive at the desired density it is necessary that the operation should occupy about eighteen hours. The actual time occupied may be more or less, influenced as it is by the kind of ammonia used, by the

[1] *Rev. Gen. Mat. Col.*, 1900, p. 267.

combined surface area of the copper presented to attack, etc. For example, if the copper has not been attacked by a preceding oxidation, and if the apparatus is new and being used for the first time, it is quite possible that the time required may be even thirty-six hours. The time taken, however, has no influence on the quality of the solution, provided the work is carried out under the proper conditions of temperature, pressure, and density.

In some works the copper oxide is prepared by intermittent operations —that is to say, after the apparatus has been in operation about three hours, it is allowed to stand for two or three hours, and so on until the required density is obtained. It is understood that the temperature remains approximately at 4° C. during the time that the apparatus is

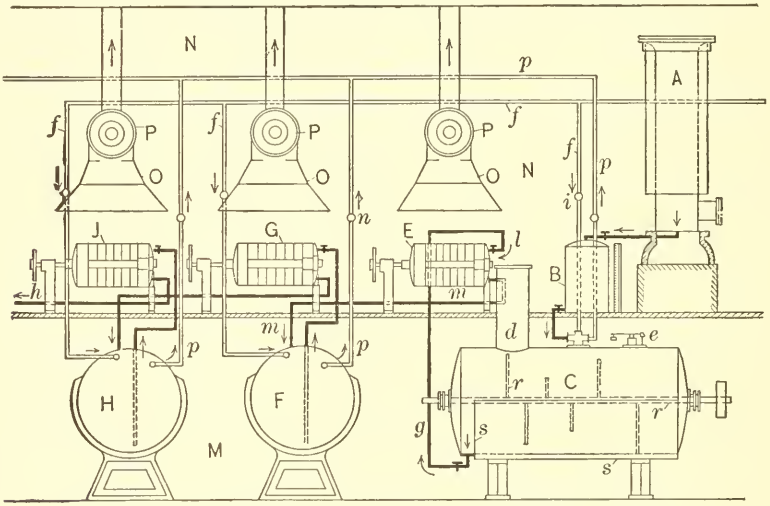


Fig. 272.—Installation for Preparing Cuprate Silk. (Foltzer.)

standing, as well as when it is in work. To secure this constant temperature, a current of cooled water, coming from a freezing machine, is made to circulate between the two covers or jackets of the cylinder. The cylinder is charged with a fresh supply of dissolved copper every ten days.

The ammoniacal copper oxide prepared in the cylinder is run into the graduated reservoir, so that the quantity may be determined; then it is transferred from the reservoir to the mixing tank (*C*) (Fig. 272) for dissolving the cotton. The mixing tank is a large horizontal iron cylinder in which is an agitator revolving at 55 to 60 revolutions per minute, thus keeping the ammoniacal copper oxide in motion, and facilitating the solution of the cotton. Although this mixing tank is situated in the basement to avoid extreme variations of temperature, it is, in addition, provided with a double cover, in order that the solution which is present

may, by cooling, be kept constantly at the temperature of 4° C. (41° F.). On the mixing tank is a dome (*d*) with a manhole through which the cotton is introduced into the mixing tank. This opening is provided with a lid or cover which may be closed rapidly and fastened down. When the copper oxide dissolved in the ammonia is in the mixing tank, and before the cotton is introduced, a very small quantity of a solution of caustic soda is added to the solution: the whole is stirred for a minute, and then only, while the agitators are in motion, is the cotton introduced. The usual quantity is from 15.4 to 16.6 lbs. of cotton for 22 gallons of solution. These quantities, however, may be varied according to the moisture which the cotton contains, and even according to the humidity of the surrounding atmosphere.

If the solution is properly prepared, the cotton must be completely dissolved, and must "draw out" or spin after having been worked seven hours. It has been shown by practice that the rapidity with which the cotton dissolves increases with its degree of whiteness or of bleaching; the process of solution may take even twenty-five hours if the cotton has not been sufficiently bleached.

The degree of fluidity is of so much importance that the chemist or director of the establishment must test it himself, and not leave this task to the foreman. The correct degree of fluidity may also be determined by pouring 4 or 5 cc. of the solution into a glass-stoppered bottle; then by holding the bottle upside down, it can be seen if the solution flows slowly so as to form a continuous thread or thin streak. If, on the contrary, the substance drops or forms an intermittent thread, it has not attained the degree of fluidity which is necessary for spinning. This degree of fluidity may also be determined in a more accurate manner. For example, a graduated glass tube tapering to a point at the bottom (a kind of burette) is filled with the solution; then by noting the time which it takes to run out a given quantity of the different solutions, it is possible to construct a table of reference which would indicate the fluidity of such solutions. It is a good practice to note daily the fluidity of the solution that is being prepared for spinning.

In Linkmeyer's process the cuprammonium solution of cellulose is coagulated by passage through a solution of caustic soda. This forms a copper-alkali-cellulose. This compound is then dissociated by treatment with water and the precipitated copper oxide is removed from the fiber by dilute acid.

In Thiele's process (*cellulo silk*) a concentrated cuprammonium solution of cellulose is passed through wide openings into a liquid (NaOH of 39° Bé.) which slowly coagulates the cellulose. The threads are drawn out to extreme fineness by means of a glass roller revolving in acid.

The cuprammonium solutions of cellulose are rather unstable, being

rapidly precipitated by the addition of neutral dehydrating agents such as alcohol, sodium chloride, etc. A flocculent jelly consisting of cellulose hydrate is formed. The cuprammonium solution of cellulose is extremely sensitive to the action of oxygen and to light; the cellulose complex in solution is degraded and the change is shown by loss of viscosity of the solution.

When a cuprammonium solution of cellulose is treated with zinc, the copper is precipitated and there is formed a colorless solution of zinc ammonium cellulose.

For the successful operation of the cuprammonium process a uniformly low temperature is required and a certain fixed ratio between the amounts of copper, ammonia, and cellulose employed.

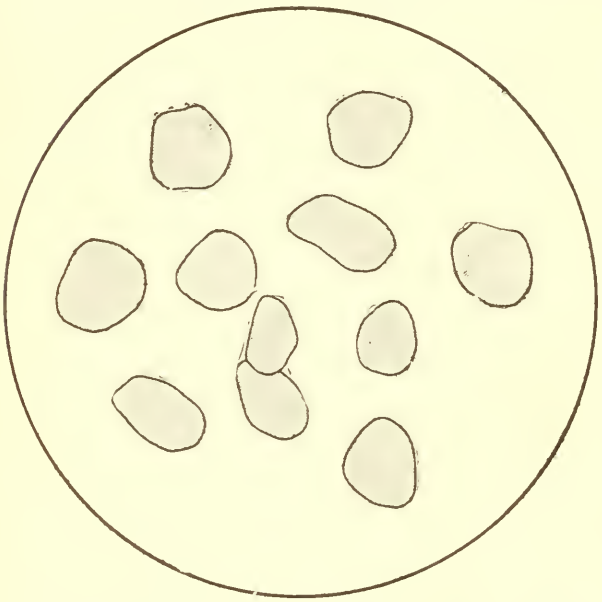


Fig. 273.—Cross-sections of Cuprate Silk. (×250.) (Micrograph by author.)

Frémery and Urban state that cellulose which has been parchmentised by treatment with concentrated sulfuric acid, and which is designated generally by the name of amyloid, dissolves in ammoniacal copper oxide solution in a much higher proportion than does cellulose which has not been prepared under these conditions. Thus, for example, parchment paper produced by means of sulfuric acid, or by zinc chloride, dissolves in a proportion of 10 percent and over. A solution of amyloid of this nature can be used for the manufacture of artificial silk of the same count as is made from a solution of cellulose. It will thus be seen that hydrocellulose dissolves in a proportion as high as that of cellulose prepared by an energetic bleaching process. Hydrocellulose can be obtained by treating pure cleaned cellulose, say cotton wadding, with sulfuric acid at 3 percent, pressing it without washing, and leaving it in contact with the air to dry. After the substance has been dried completely at a temperature of 40° C.

it is washed and dried again. For the economical operation of the cuprate process it is also necessary to have a very complete recovery of the by-products. These include the ammonia and the copper which are used in the manufacture of the silk, and both of which are rather costly. Foltzer[1] makes the following comments on the recovery of these by-products.

(*a*) The first by-product recovered is the ammonia gas, which is carried away by the air used for oxidation in the formation of ammoniacal copper oxide. This ammonia vapor is simply collected in water, or else in concentrated sulfuric acid, with the formation of ammonium sulfate.

(*b*) The recovery of the copper and of the ammonia contained in the precipitating liquids. The methods of recovery of these by-products differ according as sulfuric acid, soda, or potash is used.

Let us consider first the method of recovery of copper and of ammonia from a sulfuric acid solution. The acidulated water charged with copper and ammonium sulfate, as well as the very weak sulfuric acid which has been used for precipitation in the spinning frame, and which is also charged with copper and ammonia, is forced forward by a lead injector into a large wooden cistern. In these cisterns the copper is recovered by immersing bars of iron, as free as possible from rust, into the acid. The copper which is deposited is removed periodically, dried, and sold; or it can be employed again in the manufacture of the ammoniacal copper oxide.

When the copper has been thus recovered, preparations are made for recovering the ammonia; this may be accomplished in several ways; the simplest method being to evaporate the liquid, say in a Kestner evaporating apparatus, or else in a lead-lined cistern provided with a steam coil. The ammonium sulfate is deposited as the evaporation proceeds, and, after having been dried, is then sold. It is a good plan to filter the liquid before evaporation in order to arrest particles of iron oxide, of copper, and of other impurities which would stain the salt. It is important that the yield of ammonium sulfate should approach as nearly as possible that amount which, theoretically, would be obtained from the quantity of ammonia employed. One liter (0.22 gallon) of ammonia at 20° Bé. should produce 870 grams (1.9 lb.) of ammonium sulfate.

(*c*) When the coagulation at the spinning frame is effected by means of soda or potash, the copper is removed advantageously by electrolysis, and the ammonia is obtained by evaporation. R. Linkmeyer,[2] proposed to recover part of the copper by the introduction of flakes of cotton cellulose into the precipitation bath; the cellulose retains the copper, and could be used for solution in ammoniacal copper oxide.

(*d*) E. Crumière, of Paris, has suggested a method of removing the

[1] *Textile Manufacturer.* [2] *Fr. Pat.* 353,187.

copper from the threads, and at the same time of recovering the copper by means of an electric current, as had already been proposed in 1890 by Henri Despeissis. In the Crumière factory, however, the process is carried out as follows: The removal of the copper from the artificial silk threads or from artificial hair is effected as usual by the action of dilute acid; we should mention in passing, however, that the process is relatively long and costly. As the threads in formation lack solidity, they are wound on to bobbins before being freed from copper; but, as already stated, the action of the acid for the removal of copper is slow, especially on the inner layers of threads on the bobbins; in addition, large quantities of acid are required, which are rapidly used up, and which must be often renewed. By the Crumière invention it is possible to remove the copper almost instantaneously, and with much smaller quantities of acid. In addition to the quick recovery of the copper, the liquid can be used a large number of times. The new process consists in placing the bobbins of silk, containing after precipitation ammonia and copper, into a bath filled with acid—for example, sulfuric acid diluted with water—and in passing an electric current through this liquid. The threads lose their color immediately, the copper being dissolved by the acid, and carried to the cathodes, where it is deposited, whilst the acid employed is regenerated continuously. The silk which has thus been freed from copper is then washed in water and dried under tension. The Crumière processes are conducted in the works of a French company at Flaviac (Ardéche) and at Ilysskow in Poland.

La Société Anonyme Le Crinoid of Rouen reduces the copper salts in the alkaline baths by adding $1\frac{1}{2}$ percent of a solution of formaldehyde to the precipitating liquid, which itself is kept at a temperature of 40° C.

In cuprate silk manufacture, when the thread was spun into sulfuric acid, the recovery of the copper and the ammonia was rather simple. The copper was recovered by electrolysis of the solution or more simply by treatment with iron. The remaining solution of sulfate of ammonia was mixed with lime and then distilled to recover the ammonia. Cuprate silk spun into sulfuric acid, however, often presented the defect of glittering points or specks produced by the pressure exercised by one layer of the freshly precipitated and soft gelatinous thread on the one below in drying, for shrinkage had to be prevented by using an inflexible reel or support. If shrinkage were permitted in the drying of the cuprate silk the luster would be much impaired and the fiber would be brittle. When cuprate silk is spun into a bath of soda lye, the recovery of the copper and the ammonia is also very simple, the ammonia being expelled by warming the lye and being absorbed in sulfuric acid. The copper hydroxide is extracted with sulfuric acid and precipitated in the form of metallic copper by electrolysis or with iron. While fine threads may

easily be produced with cuprate silk by spinning into acid, thick threads, like artificial horsehair or monofil, cannot be made in good quality. The alkaline spinning process has proved to be absolutely necessary for this class of work. The products made with soda lye, however, are not so lustrous as those made with the acid liquor, also with the alkaline bath threads from apertures of less than 0.2 mm. cannot be satisfactorily made. This difficulty, however, has been overcome by using, instead of soda lye alone, a mixture containing cane sugar or glucose dissolved in soda lye. This permits of the spinning of highly lustrous coarse threads as well as of very fine threads. On merely washing the precipitated thread with water for a short time a transparent thread of uniform composition is produced. The copper seems to be in solid solution, both in the sugar and the cellulose and combined with both. The threads can be dried and kept for a long time and knitted or woven without undergoing decomposition; the solid solution is decomposed when washed with more and hotter water, the sugar is washed out and the copper hydroxide is converted into black oxide of copper. Some of the copper, however, in the first alkaline bath splits off and is reduced to red cuprous oxide by the sugar, and this accumulates in the bottom of the spinning vessel. The copper residues left in the threads after washing are removed, along with the remaining ammonia, by treatment with dilute sulfuric acid.

In the Thiele process for cuprate silk the so-called " stretch spinning " method was employed, in which weak precipitants were used. This process was tried out in factories at Great Yarmouth in England and in Hal in Belgium, but without good results. Bronnert, however, thinks that the fault was not in the method but in the imperfect manner of operating, as the process has been quite successful at Barmen, giving the so-called " Eagle " silk, which is formed by single fine filaments of 2 to 3 deniers. The Thiele process is notable for the fact that no real precipitant is used but only water. The silk is spun from apertures of 0.8 to 1 mm. diameter, passes through a column of water in suspension, and is elongated to a fineness of about $2\frac{1}{2}$ deniers. The ammonia is removed by the water which flows out with the threads, while the copper is removed later by treatment with dilute sulfuric acid. This method produces the finest threads of any but there is considerable variation in the count, and the luster is not as high as with the other processes.

Cuprate silk has the advantage over the other varieties of artificial silk in having a greater resistance to water; it is better in this respect than denitrated nitro silk or even acetate silk, and is slightly better than most viscose silk. This superiority of cuprate silk is only present, however, when cotton is used as the raw material for the preparation of the cellulose solution. It is on account of its better resistance to water that cuprate silk is still produced and is preferred for certain purposes.[1]

[1] See Bronnert, *Jour. Soc. Dyers & Col.*, 1922, p. 157.

6. Viscose Silk.—This is prepared from solutions of cellulose thiocarbonate and is the principal form in which artificial silk is made at the present time, both in American and Europe.[1]

Viscose itself is prepared by the action of caustic alkali and carbon disulfide on mercerised cellulose, a gelatinous mass being obtained which is readily soluble in water, giving a yellowish and very viscous solution. In practice there are employed one molecule of cellulose, two molecules of caustic soda, one molecule of carbon disulfide, and thirty to forty molecules of water. The corresponding molecular weights of these ingredients are as follows:

1 cellulose, $C_6H_{10}O_5$	165
2 caustic soda, 2NaOH	80
1 carbon disulfide, CS_2	76
30–40 water, 30–40 H_2O	540–720

Viscose is an alkaline xanthate of cellulose, and its industrial manufacture is carried out in the following general manner: Sheets of pure bleached sulfite wood-pulp are ground up with solid caustic soda in a circular edge-roller mill until a finely divided crumb-like mass is obtained. The product in this form is known as "crumbs," and consists of alkali-cellulose. This operation should be so conducted as to leave for 300 parts of alkali-cellulose, 100 parts of cellulose, and 200 parts of caustic soda of 26° Bé. That is to say, the proportion should be about 100 parts of dry cellulose to 48.5 parts of caustic soda (NaOH). The caustic soda should be pure and free from carbonate in order to obtain good results.

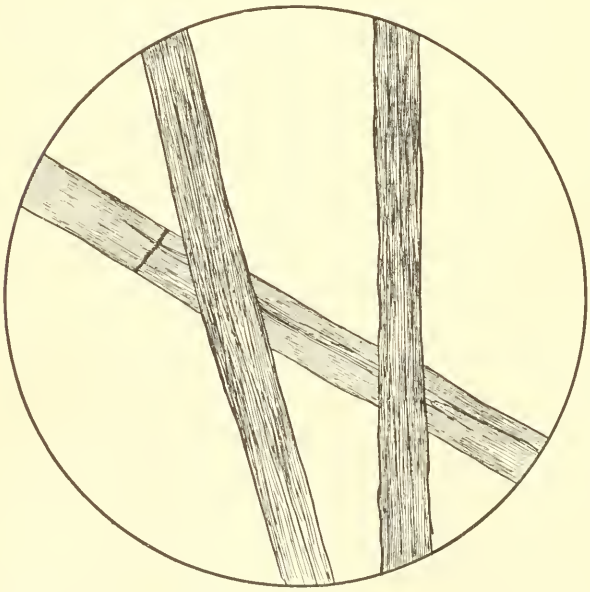


Fig. 274.—Viscose Silk. (×350.) (Micrograph by author.)

[1] Stearn, *Brit. Pat.* 1020 of 1898.

The excess of moisture is then pressed out, and the material is allowed to lie for some time.

The alkali-cellulose is then placed in an iron vat provided with a rotary stirrer, where it is treated with carbon disulfide. For each 100 parts of cellulose there should be used 34.5 parts of carbon disulfide. The resulting mass is translucent and gelatinous in appearance and of a clear brown color and is known by the name of viscose. The viscose prepared from cotton is of a brownish color, while that prepared from wood-pulp is more of an orange color.

Immediately after its formation, the viscose is dissolved in water and then filtered in order to remove any cellulose fiber which may not have undergone chemical transformation. For the successful preparation of artificial silk it is necessary that the filtering should be as perfect as possible, for the occurrence of any fibers in the solution will cause stoppages of the spinnerets and consequently breaks in the filaments. After filtering the viscose solution is thoroughly mixed. The freshly prepared solutions of viscose are very thick and viscous, but when allowed to "ripen" for some time they become more fluid and homogeneous. Viscose solutions are tested for degree of ripening by treatment with a 40 percent solution of acetic acid. If the viscose is not sufficiently matured it will dissolve, but if the solution has arrived at its proper condition the viscose will gradually coagulate and give a solid and coherent filament.

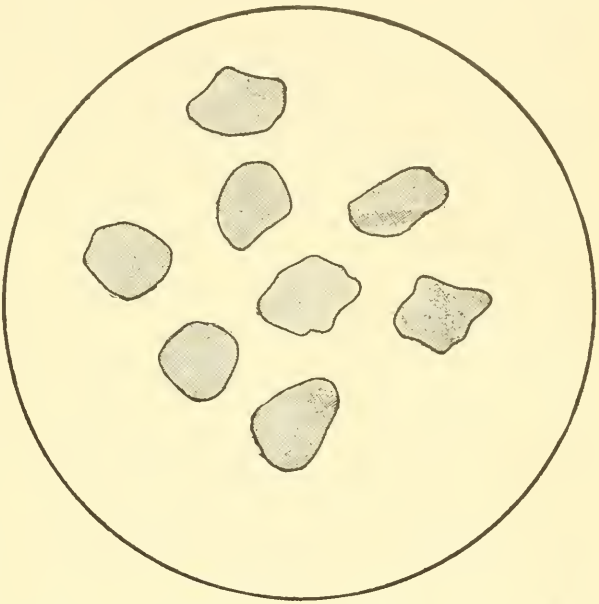


FIG. 275.—Cross-sections of Viscose Silk. (×350.) (Micrograph by author.)

When the desired degree of fluidity has been attained (which is indicated by means of a viscosimeter), the viscose solution is run into suitable reservoirs, in which it is maintained at a temperature of 32° F. Previous to passing into the spinning-machines, the solution is filtered a second time, after which it is run into an apparatus where it is subjected to high pressure

for the purpose of forcing out all air-bubbles which are liable to be retained due to the viscous nature of the solution. This latter treatment is very essential, as the presence of air-bubbles would interfer every materially with the regularity of the spun fiber.

The viscose solution then goes into an apparatus which may be called a spinning-frame. This consists of a double series of small pumps, which force the solution through platinum spinnerets pierced with very fine openings, the number of which varies with the size of the thread it is desired to produce. The production, therefore, is proportional to the number of orifices in use; the normal number being about eighteen orifices per thread, while each orifice corresponds to a daily production of about 28 grams (about 1 oz.). Each spinneret and tube which carries it are immersed in a concentrated solution of ammonium sulfate, or dilute sulfuric acid, for the purpose of coagulating the liquid jet coming from the spinneret by bringing it into immediate contact with the solution. The different filaments forming the threads are at the same time united into one single fiber, and these are carried into a solution of ferrous sulfate (copperas) in order to remove all residual matter left on the fiber from the first bath. The threads then pass into a turbine bobbin, which collects them into skeins, and at the same time gives the thread the desired degree of twist. The fiber, in the form of hanks, is then steeped in an acid solution for the purpose of neutralising any alkali left in the filaments, the excess of acid being afterward removed by washing in water. Residual sulfur compounds are removed by treatment with a solution of sodium sulfide. Sodium bisulfate as well as sodium bisulfite with aluminium sulfate are also used. The fiber at this stage has a rather pronounced yellow color, which is removed by bleaching with chloride of lime or better with a neutral solution of sodium hypochlorite. Viscose silk has a fine glossy appearance, and possesses a tensile strength about equal to that of pyroxylin silk; like the latter, however, it is also weakened when moistened with water.

According to C. F. Cross, the experimental plant for the manufacture of viscose silk, designed and erected at Kew by Stearn and Topham, and its rapid improvement to the stage of actual production of a merchantable "silk," was a marvelous example of technical insight and grasp of principle, for it comprised the use of the pump for controlling the viscose delivery for the unit multiple thread, metallic spinning nozzles with multiple perforations of minute diameter, and the centrifuge-box for collecting and laying the thread and imparting the required twist, which are employed to this day in producing what is probably the larger portion of artificial silk. These have been modified in detail by many workers, particularly by Clayton, and the number of variations patented is now considerable. The principle of parallel spinning directly on bobbins and

twisting afterwards, which was developed at an early date in the viscose factories of Germany and Italy, has survived, and is turning out the "silk" in large quantities, but experts cannot agree as to the relative merits of these two processes. The very desirable method of rotating the spinning jet itself, so as to twist the thread before winding it on to a bobbin, has attracted much inventive ingenuity, but the considerable difficulties which arise in practice are still to be overcome.

With regard to secondary details, an enormous number of variations have been proposed, but most of these show more ingenuity than knowledge of the practical problems of artificial silk manufacture. On the chemical side, almost every possible and many quite impossible substances have been proposed as additions to the viscose and to the spinning bath. Substances have been added to the viscose with the purpose of modifying the cellulose to a thread of greater softness and resistance to water, also for reducing the rate of ripening of the viscose so as to obtain a more stable product. For these and other purposes, the addition of the following have been proposed: Sodium silicate, sodium aluminate, soap, sodium thiosulfate, glycerol, glucose, urea, salts of resinic acid, phenol-formaldehyde condensation products, albumen, turpentine, and naphthenic acids.

According to Bronnert, the cross-section of viscose silk threads produced in an acid charged with an excess of neutral salt exhibit the form more or less of a star or a ribbon with serrated contours. The more salt is present the more the ribbon-like form prevails, the reason being a slower coagulation and the effect of the winding-on rollers or the tension when spinning into centrifugal boxes. This silk, however, has very good covering power, and is preferred for weaving purposes. Viscose silk spun in sulfuric acid alone has a more or less regular round contour; the same is true when bisulfites are used in the spinning bath. Threads spun in neutral or slightly acidulated ammonium salts also have a perfectly round contour.

The chemist has a greater latitude with regard to the possible components of the spinning bath and this has resulted in the following list of substances proposed for this purpose: Sulfuric, hydrochloric, formic, acetic, lactic, citric, tartaric, glycollic, and aromatic sulfonic acids; sulfates of ammonium, sodium, magnesium, iron and zinc; chlorides of sodium and ammonium; sodium sulfite, bisulfite, and thiosulfates; alcohols, starch, sugars, molasses, aniline, glycerol, aldehydes, ketones, and lignone-sulfonic lyes.

The principal development in this respect, which was foreshadowed by Stearn and Woodley [1] for spinning a purified viscose, has been the use of acid solutions for spinning so as to get a cellulose thread directly instead

[1] *Brit. Pat.* 2529 of 1902.

of a cellulose xanthate thread which has to be subjected to further treatment to regenerate the cellulose. Since then, the value of both salts and acids has been fully appreciated, and various mixtures of these two classes of substances have held the field, the use of organic substances such as glucose having proved valuable on account of their effect in modifying and softening the action of the acid constituent.

So far, viscose, in spite of its undoubted merits has not shown the facility possessed by cuprammonium solutions of being spun into very fine filaments, as is being done by Bemberg and Holken. One looks forward with interest to the working of recent patents of E. Bronnert in this connection, which claim to produce the thread in a range of 5–2 deniers and to extend the industry in the direction of substituting silk. The usual size of the viscose silk filaments has always been about 7 to 8 deniers and until recently it was not possible to produce filaments under 6 deniers on a commercial scale. Bronnert, however, has shown that fiber counts down to 0.75 denier can be made by the use of fine apertures and spinning into a bath containing a higher concentration of acid. It is necessary that this latter factor be accurately adjusted to meet the conditions for each count. Brilliancy in the fine counts, may be varied at will, and without any damage to the strength of them. To reduce brilliancy and to obtain an opaque thread it is only necessary to lower the temperature. By raising the temperature a thread of more and more luster is produced. This new viscose has a very soft touch, with an increased covering power, dyes evenly and, it is claimed, when woven does not easily crease.

The amount of free alkali and combined alkali present in viscose may be determined quantitatively through the difference in the action of organic and mineral acids on viscose. It is possible to treat a solution of viscose (cellulose xanthate) with an excess of acetic acid in order to neutralise the free alkali without attacking the alkali combined with the cellulose group. If the viscose, however, is treated with dilute sulfuric acid and boiled, the xanthate is decomposed, and thus the total alkali may be obtained. The difference in the two results gives the combined alkali.

The analysis is carried out as follows: 50 grams of the viscose are dissolved in water and made up to a volume of 500 cc. To 100 cc. of this solution is added a definite volume of semi-normal acetic acid in sufficient excess to cause total precipitation of the viscose. The precipitate is filtered off and washed with saturated brine. In the filtrate so obtained the excess of acetic acid is determined by titration with semi-normal caustic soda, using phenolphthalein as indicator. To a second 100 cc. sample of the viscose solution is added 50 cc. (or more if necessary) of normal sulfuric acid. The solution is brought to boiling, the precipitate is filtered off and washed. In the filtrate the excess of sulfuric acid is titrated with normal caustic soda using methyl orange as indicator. The

acid neutralised by the viscose gives the total alkali, and the difference between the first result and this latter gives the alkali combined as xanthate.

The amount of sulfur in viscose is determined by first oxidising to sulfate by treatment with an excess of sodium hypochlorite, then precipitating and determining by the usual gravimetric method as barium sulfate.

The determination of the viscosity of viscose solutions is an important analytical factor. This test may be made by one of several methods: (*a*) The solution of viscose is placed in a 30 cc. Mohr's burette graduated in 1/10 cc., and having an orifice 1 mm. in diameter. The time required for 30 cc. of the solution to run from the burette is noted. If this time is the same for different samples from the solution it indicates the viscose is well-ripened and homogeneous. (*b*) Another method is to employ a glass tube 3 cm. in diameter with two marks 50 cm. apart. The tube is filled with the viscose solution to the upper mark and placed in a vertical position. A small nickel ball 5 mm. in diameter is then introduced, and the time required for it to fall between the two divisions is noted. A solution in proper condition for spinning, when at a temperature of 70° F., should show sixteen to seventeen seconds for the fall of the nickel ball. (*c*) Boverton Redwood's or Engler's viscosimeter may be used. In these a definite volume of the solution to be tested is allowed to flow through a small opening and the time compared with that required for water. (*d*) In Doolittle's apparatus the viscosity is determined by the friction against a rotating weight moving in the liquid, the motion being imparted to the weight by the torsional twist of the suspending wire.

As employed for purposes of spinning, the viscose solution should contain about 6 to 7 percent of cellulose and 8 percent of caustic soda. In ripening or aging the viscose solution a temperature of about 70° F. is maintained until the liquid acquires the proper fluidity. The ripening process must then be stopped at the proper point by cooling the solution to 23° F. by refrigeration.

In the spinning of viscose silk the character of the coagulating bath has much to do with the contour of the fiber section. In the Courtauld process for making the usual threads of 8 deniers, a bath containing only about 8 percent of sulfuric acid together with sulfate and glucose is used; the section of this fiber is irregular in outline and not rounded or oval. The weak acid bath is only suitable when spinning into centrifugal boxes where the individual filaments are twisted together at once, as in the Courtauld method. In the Bronnert process the bath contains 16 to 18 percent of sulfuric acid together with an excess of sulfate, and the spool-spinning method is used. This system is particularly of use where silk of lower deniers (from 60 to 120) has to be produced.

A viscose solution will begin to coagulate seven to eight days after its preparation. The coagulum will at first occupy the entire volume of the solution, but soon contracts little by little. After forty-seven days the shrunken coagulum of cellulose hydrate occupies only 30 percent of the original volume. It then forms a rather hard mass, and is known as **viscolith.**

When viscose silk is treated with formaldehyde in the presence of acids and dehydrating agents it is said that the thread acquires a greater resistance to moisture, and consequently shows less loss of tensile strength when wetted.[1] The artificial silk is placed in a bath containing 1–10 parts of formaldehyde and 90–99 parts of acetic acid (40 percent). This process is known as "*sthenosage*" or strengthening.

Cross and Bevan[2] give the following table showing the effect of the sthenosage process on the quality of artificial silk:

	Breaking Strain, Grams per Unit Denier.		Elasticity, Percent.	
	Air-dry.	Wetted.	Air-dry.	Wetted.
Artificial silk of collodion, cuprammonium and viscose methods	1.25	0.37	12.2	9.0
Sthénosé products	1.6	1.1	7.8	7.6

The necessity of "aging" or "ripening" viscose solutions previous to spinning has been obviated by the addition of a neutral salt[3] (such as

[1] Eschalier, *Fr. Pat.* 374,724.

[2] *Jour. Soc. Chem. Ind.*, 1908, p. 1189.

[3] Ernst (*U. S. Pat.* 863,793 of 1907). It is here pointed out that if the viscose formed by dissolving the cellulose xanthate in a suitable solvent be allowed to stand or "age" for a sufficient length of time, it will of itself change or coagulate; hence it will be apparent that the function of the "aging" process is to allow the viscose to approach but not quite reach that critical point at which it of itself coagulates, so that all that is needed to transform it into a filament is to spin it into a weak neutralising bath. On account of the fact, however, that it is impossible to obtain absolutely uniform cellulose xanthate, the result is that during the "aging" process certain portions of the viscose will age too much, and particles will frequently coagulate which greatly interferes with the spinning operations, by clodding the spinneret tubes and therefore depreciating the quality of the filaments produced. The object is, first, to produce a viscose which does not require to be aged but nevertheless will coagulate immediately when the filament is brought into a weak acid bath, although the viscose be fresh, and to preserve the viscose, and second, to so check the action of the carbon bisulfide as to enable the viscose to be stored until needed for spinning. Freshly formed viscose ordinarily would be coagulated by ejecting it through a spinneret into a strong acid bath, but the filament produced could not be formed commercially as

sodium sulfite or sodium silicate) to the solvent for the cellulose xanthate before the latter is added. This imparts to the viscose solution the property of immediately coagulating when ejected into a weak acid bath.

By coating a cotton thread with a solution of viscose an imitation horsehair can be obtained. This product is known under the name of " viscelline " yarn.

According to Foltzer (*Textile Manufacturer*), the raw material for the manufacture of viscose is wood-pulp freed from grease and bleached, similar to that which is used in the manufacture of paper. It is used in preference to cotton, because it is cheaper. Although this pulp is often delivered ready for use at the artificial-silk factory, it is always a wise plan first to wash it well with a large quantity of water. In general this wood-pulp is not sufficiently free from grease; in this state it cannot be satisfactorily employed for the viscose process, and should be submitted to a process somewhat similar to the following: In a boiling kier of a similar type to that which is used in the preparation of cotton the wood-pulp is subjected to boiling for about three and one-half hours in a bath of soda of $1\frac{1}{2}°$ to 2° Bé. Ferruginous or calcareous water must on no account be used in this process. After the pulp has been boiled, the soda lye is allowed to flow out, the substance is well rinsed with water, preferably at a temperature of 25° to 30° C., and finally it is placed in a hydroextractor. The wood-pulp thus treated is transformed into alkali-cellulose in the following manner: After the processes of washing and hydroextracting, the pulp contains from 40 to 50 percent of water, and it is essential that this percentage should be determined accurately. For this purpose a sample of the partly dried pulp is heated at a temperature of 103° to 105° C. until there is no further diminution in weight. The difference in the weights of the partly dried and perfectly dried pulp clearly gives the amount of water, and with tables, such as are used in the conditioning of yarns and fibers,

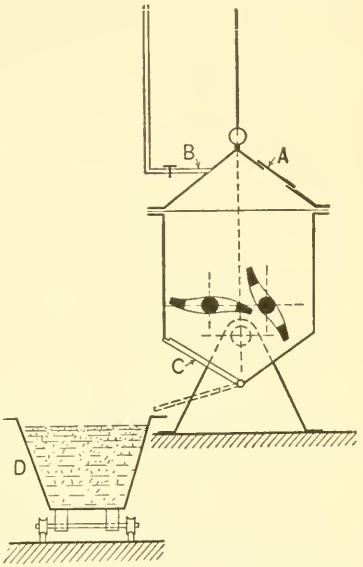


FIG. 276.—Mixing Tank for Viscose. (Foltzer.)

by this process it would be very weak and possess little or no elasticity. To produce a strong elastic thread the viscose must be ejected into a weak acid bath; hence it is necessary to employ a viscose solution which will coagulate immediately into a filament when ejected into the weak acid bath.

the percentage of moisture can be obtained. According to the researches of Beltzer, 200 grams of caustic soda at 26° Bé. are required to transform 100 grams of cellulose (in this case wood-pulp) into 300 grams of alkali cellulose; but the percentage of moisture in the partly dried pulp must be taken into account in order to arrive at the exact amount of caustic soda required. The duration of the action of the caustic soda on the pulp must be extended in the manufacture until a uniform alkali-cellulose is obtained, and to achieve this end it is necessary from time to time to make trials to determine when the impregnation is complete. This operation demands much care and attention when the manufacture is carried out on a large scale, and it is necessary to choose mixing tanks in which the work may be quickly performed, and in which all the cellulose will be impregnated uniformly in a relatively short time—about three and one-quarter hours. The mixing-tanks described and illustrated for the manufacture of artificial silk by the cuprammonium process are not suitable for the viscose industry; it is advisable for this process to use mixing-tanks somewhat similar to that illustrated in Fig. 276. The wood-pulp is introduced into the cylinder (*A*); the apparatus is then put into motion and at the same time the soda liquid is allowed to enter by pipe (*B*). The alkali-cellulose obtained by this process is in the form of a bleached pulp, which is removed from the mixing-tank at the opening (*C*) (where the hinged door is shown in the dotted position), into the wagon (*D*), in which it is carted to the apparatus illustrated in Fig. 277, where it is transformed into viscose. The interior case of the jacketed cylinder is lined with nickel. The alkali-cellulose previously prepared for transformation into viscose paste is introduced by the opening (*B*). The lid (*B*) is

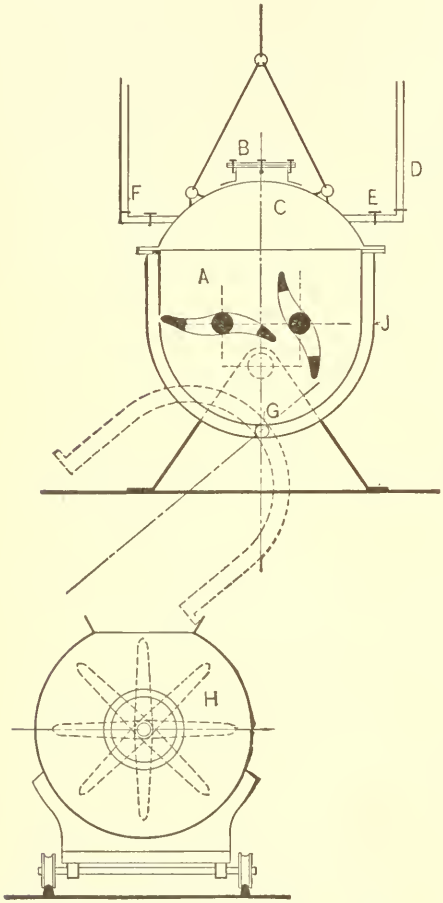


Fig. 277.—Apparatus for Preparing Viscose. (Foltzer.)

hermetically sealed; the agitators are then set in motion, and are kept rotating for twenty to thirty minutes. Carbon disulfide flows through the pipe (*D*), and the necessary quantity is admitted into tank (*A*) by opening the valve (*E*). For the transformation of 200 kilos. of alkali-cellulose, 34 kilos. of carbon disulfide are required. The ingredients must then be mixed for three to four hours in order to obtain a homogeneous substance which has a dark yellowish orange color. After the process of mixing has been in operation for the time indicated, 200 kilos. of caustic soda, made up into a 15 percent solution, are added to the mixture, and the mixing is continued until a uniform pulp is obtained; the caustic soda comes from a graduated reservoir through pipe (*F*). The viscose thus obtained is then deposited into the mixing-tank (*H*), mounted on a wagon. The viscose is then diluted with water in mixing-tank (*H*), in the proportion of 185 liters of water to 100 kilos. of viscose pulp. It is desirable during all these operations that the temperature should not exceed 25° C., and when these operations are completed that the mixing-tank (*A*) should be cooled by allowing a freezing mixture to flow through the jacketed part (*J*). The solution is then mixed for four hours in the apparatus (*H*), and finally allowed to stand for ten to fourteen hours; during this time liquefaction proceeds gradually, and it must be arrested when the consistency of the substance is most favorable for transformation into threads; this point is determined by means of a *viscosimeter*. If this point is passed, liquefaction continues, followed some time after by decomposition, with later a solid deposit of cellulose. Before the solution is spun—an operation which is performed under a pressure of 3 to 4 atmospheres—it is filtered and the air cells are removed from it by an aspirator.

7. Acetate Silk.—The acetate of cellulose has also been used as a basis for the manufacture of artificial silk.[1] It is dissolved in a suitable solvent [2] and spun in the same manner as collodion silk, the thread being coagulated by passing through a bath of water. With collodion silk the weight of the product obtained (after denitration) is scarcely equal to that of the cellulose used, whereas with acetyl cellulose the weight of the resulting silk corresponds to about twice the weight of the cellulose taken. The silk made from acetyl cellulose, however, is less stable toward acids and alkalies than collodion silk, neither does it dye as readily; and the dyeing is best done by adding the coloring matter to the solution before spinning. The silk made from acetyl cellulose is known as "cellestron," "celanese," or "acetate" silk, and is used for covering electric wires, as it has remarkable insulating properties.

[1] Acetate silk has been made experimentally by the Henckel Donnersmarck works at Stettin, and is now made on a fair-sized commercial scale by the British Cellulose Products Co. The production of acetate silk is also being attempted in America.

[2] Chloroform, ethyl acetate and alcohol, or acetic acid may be employed as solvents for cellulose acetate.

The chief advantage claimed for acetate silk over other forms of artificial silk is that it is not so much affected by either hot or cold water.[1] The acetate silk, however, that has appeared commercially in trade does not seem to have much greater strength either dry or wet than the other forms of cellulose silk.[2]

Cellulose acetate solutions may also be employed for coating cotton threads to produce an artificial horsehair impervious to water.[3]

The single filaments of acetate silk under the microscope appear as uniform cylinders with occasional band-like thickenings. The cross-section is oval to circular, and the average diameter is 42.3 microns. The strength of a thread of 18 single filaments was found to be 226 grams when dry and 128 grams when wetted. Acetate silk is soluble in cold acetic acid, but insoluble in ammoniacal copper hydroxide. Iodine and sulfuric acid gives a yellow color, as does also zinc chlor-iodide. It burns quickly with a disagreeable odor and leaves a massive charcoal residue. It is distinguished from all other artificial silks by its low density (1.25) and by not swelling in water.[4]

The production of soluble compounds of cellulose acetate by the action

[1] Cellulose acetate does not swell in pure water or absolute alcohol, but swells greatly in mixtures of water with alcohol or other organic liquids. Two methods are described by which the degree of swelling of the colloid was measured. "Unswollen" cellulose acetate is colored only very slowly in an aqueous dye bath at 25° C.; with slightly swollen cellulose acetate the maximum color is reached in several months, and with fully swollen cellulose acetate the limiting value of the color under the same conditions is attained in a few minutes. Raising the temperature hastens these color processes. The significance of the relation between speed of coloration and degree of swelling for the dyeing of textile fibers and staining in microscope work is shown. Unswollen cellulose acetate is very difficultly saponifiable, but swollen cellulose acetate is completely saponified by 0.5N potassium hydroxide in a few hours at room temperature, and the velocity of the reaction increases with the degree of swelling. A convenient and accurate method of acetyl determination is based on the behavior of swollen cellulose acetate toward dilute aqueous alkalies at room temperature.

[2] In the development of cellulose acetate for silk it was hoped to take advantage of certain facts such as the following: (1) it is of notably lower specific weight, and approximates that of natural silk; (2) as an ester derivative it should have a resistance to water much greater than even normal cellulose; (3) as an ester, it represents a considerable increase of weight in relation to the raw material, whereas all other forms of cellulose silk represent a lower weight; (4) the thread once formed is in its saleable form, requiring only the mechanical treatments incidental to finish. The thread of acetate silk is produced at the rate of 100 meters per minute, whereas viscose silk can be spun only at a rate of 45 to 50 meters per minute; therefore a greater production per spinneret may be obtained from acetate silk. But the cellulose acetate fulfilling the requirements for spinning into a thread has colloidal structural characteristics inferior to the nitric acid ester, and the acetate silk fails to show superiority to the other cellulose silks in tenacity in either the dry or wet state.

[3] See *Fr. Pat.* 369,123 of 1906 and 376,578 of 1907.

[4] Herzog, *Chem. Zeit.*, 1910, p. 347.

of acetic anhydride and glacial acetic acid on cotton, always requires the presence of a so-called catalytic agent. These catalytic agents as specified in a large number of patents may be grouped in three classes: free mineral acids, weaker acids and acid salts, and neutral salts which are readily dissociated. Schwalbe [1] discusses the mechanism of these reactions and points out that the production of the cellulose acetate is always accompanied by a more or less profound modification of the cellulose, as evidenced by the copper reducing properties of the cellulose residue after the saponification of the acetate. Of the mineral acid group of catalytic agents, sulfuric acid is by far the most important, and its application is amply illustrated in the patents of Lederer and Bayer & Co. The principal representatives of the second group are the phenolsulfonic acid of Mork's patent, and the halogenated fatty acids of Knoll & Co. Schwalbe attributes the catalytic effect of these bodies to the presence of limited quantities of free mineral acid. Representatives of the third group include such bodies as ferrous sulfate, ferric chloride, diethylamine sulfate, etc., found chiefly in Knoll & Co.'s patents. These so-called neutral salts possess weak bases and free mineral acids are produced from them by dissociation.

Cellulose acetate is not soluble in aqueous liquids, and for this reason the production of filaments from it largely follows the Chardonnet process; also, for the same reason, the thread produced from it is soluble in or softened by numerous organic solvents. The thread is stated to be impervious to water; this, however, does not cause its strength when wet to be greater than that of viscose silk, and in the dry state its tenacity is considerably lower. The production of acetate silk is apparently still in the experimental stage, for it cannot yet be obtained for commercial purposes in any large quantity, although small quantities have been exhibited, and the samples which are obtainable possess properties of which most users, whether textile workers or dyers, will probably need considerable experience before they will be persuaded to accept them as desirable in a standard yarn. It is, for instance, unique in its dyeing properties, in that with ordinary methods it can be dyed only by means of basic dyes, which are among the most fugitive of coloring matters;[2] direct cotton colors it refuses to take up, and the dyeing of fabric composed of cotton and artificial silk with direct colors, a very usual procedure,

[1] *Zeit. angew. Chem.*, 1910, p. 435.

[2] According to *Brit. Pat.* 158,340, cellulose acetate silk may be dyed after treatment with a solution of ammonium thiocyanate. This treatment increases its affinity for all classes of dyestuffs. Fabrics containing cellulose acetate silk are immersed for two to sixty minutes at ordinary temperature in a 5 to 25 percent solution of ammonium sulfocyanide, thoroughly washed, and dyed in the usual way. The ammonium thiocyanate may, in some cases, be added to the dyebath. Sodium, potassium, and calcium thiocyanates may also be used.

is not possible in the case of acetate silk. If this is attempted with acetate silk, the cotton takes up the color normally, but the acetate combines only with the basic impurities in the dye, with the result that the former may be the desired navy blue while the latter is perhaps a dirty yellow shade, or while the former is black, the latter is brick-red. When dyeing is attempted with vat colors of the indanthrene type, which are coming into great demand on account of their remarkable fastness and consequent suitability for washable materials, cellulose acetate silk sometimes is partly decomposed, and loses its luster and silk-like properties. Considerable effort has been made to devise methods for the satisfactory dyeing of acetate silk with substantive, and it has been found that a treatment of the fiber with a solution of caustic soda (saponification) previous to dyeing gives very good results without materially affecting the quality of the silk. It is understood that the manufacturers of this silk now place the treated material on the market ready for dyeing.

Acetate silk has a very low electric conductivity, and consequently may prove to be a very useful material for the covering of electric wires and for other insulating purposes; in such cases, where coloring is often desirable, but numerous or exact shades are not necessary, the methods and dyestuffs available may give sufficiently good results.[1]

Another use to which cellulose acetate has been put is that of coating cotton or silk threads with soluble acetates in admixture with a metal powder. To increase the pliability of the thread, certain substances such as acetin and acetyl-benzyl-orthotoluidine are added.[2] The product was known as *Bayko* yarn and gave a beautiful imitation of gold and silver threads, which, however could be toned to any desired shade and used for ornamental fabrics. Another use of cellulose acetate was to make so-called "solid" alcohol, or alcohol tablets. These consist of 10 percent of cellulose acetate and 90 percent of alcohol, and have proved to be very useful where the liquid alcohol cannot be conveniently transported. Another interesting use of cellulose acetate is in the product known as *Sericose L.* This consists of the tri-acetate soluble in alcohol and acetic acid and is employed as a thickener and agglutinant for obtaining various printing effects, especially for making imitation Swiss polka dot fabric.

Within the last decade acetate of cellulose has been largely used in the manufacture of films and for waterproofing fabrics. There may be mentioned among others, the films of the Boroid Company, London; Lumière and Planchon, of Lyons; la Société "Cellon," which employs the Eichengrün patents; and la Société "Cellophane," at Thaon-les-Vosges.

8. Gelatine Silk.—This is a thread of gelatine, and consequently differs from the other artificial silks in that it consists of animal tissue and

[1] See *Jour. Soc. Chem. Ind.*, 1920, p. 267. [2] See *Brit. Pat.* 11,354 of 1909.

not vegetable. Due to this circumstance, it has more analogy chemically to true silk than the various cellulose silks. The manufacture of this fiber known as *vanduara* silk was conducted by forcing an aqueous solution of gelatine through a fine capillary tube; the thread so produced is carried on an endless band through a drying-chamber. The soft gelatine thread, of course, flattens out considerably during this operation, hence the silk eventually forms a flat, ribbonlike fiber. After drying and properly reeling the fiber is treated with vapor of formaldehyde, which causes the gelatine to become insoluble in water. By varying the pressure on the gelatine solution, whereby it is forced through the capillary tube, the thickness of the fiber may be increased or diminished. The same result may be attained by varying the speed of the endless band which carries the thread after coming from the capillary tube. The silk may be dyed either in the ordinary way in skein form after reeling, or the gelatine solution may be colored before the thread is drawn out. The fiber is very lustrous, and if the filaments are drawn fine enough the silk is soft and pliable.

Vanduara silk is an English invention, the patentee being Adam Millar.[1] The silk has never appeared on the market as a commercial commodity, and the process does not seem to have met with any marked degree of success. Another process giving a thread of a similar character was that of Todtenhaupt.[2] The latter uses an alkaline solution of casein.

Another interesting form of artificial silk is that known as Lowe silk; it consists of a real silk cocoon filament surrounded by a solution of artificial silk so that the two conglomerate together into one continuous fiber. It has the handle and luster of real silk and also dyes well. So far it is only in the experimental stage and has not been placed on the market commercially.

9. Properties of Artificial Silk.—The chief drawback to the commercial success of artificial silk has been its behavior with water. When wetted with water the fiber swells up to a considerable extent, pyroxylin silk increasing in thickness by over 60 percent in an hour and viscose silk by about 45 percent in ten minutes. Fibers of ordinary silk and also tussah silk remain practically unaltered when wetted. When wetted the fiber of artificial silk loses its original strength to such a degree that it must be handled with great care. Soap solutions and dilute acids have no injurious effect, but alkaline solutions rapidly disintegrate the fiber and finally dissolve it completely. Strehlenert has endeavored to prevent the loss of strength in collodion silk when wetted by the addition of formaldehyde to the collodion solution.[3] This process, however, does not appear to have been a success.

[1] *Brit. Pat.* 15,522 of 1894.
[2] *Brit. Pat.* 25,296 of 1904.
[3] *Brit. Pat.* 22,540 of 1896.

The material is rather difficult to dye, on account of the weakening action of water, and the operation must be carried out with great care. The dyeing is accomplished without the addition of either soap or acid to the bath. The basic coloring matters and some of the direct cotton colors appear to be the best dyestuffs to employ.

Another feature in which artificial silk is inferior to natural silk is its lack of " covering power." That is to say, the filaments of true silk form a more open thread which presents a thicker appearance than a thread of artificial silk of the same weight. Consequently a fabric woven from real silk is more solid in appearance, or better covered than a corresponding fabric made of artificial silk threads of the same size and weight.

Most of the artificial silk produced at the present time is spun in about 150 denier size, corresponding to about 37's cotton yarn. Silk of 120 denier size is also used. The number of individual filaments in a thread of 120 denier ranges from 16 to 25, hence the size of the individual fiber is about 5–8 denier, in comparison with real silk which averages 1.25 denier to each filament. Thiele's silk (cellulo) has been made as fine as 30–50 denier and containing 45–60 filaments, making each of the latter 0.5–1.2 denier in size, or even finer than the filament of natural silk. The finer the denier, the greater covering power of the silk, but also the higher its cost. There is very little demand at the present time for artificial silk finer than 120 denier.

In their dyeing properties the artificial silks are in general similar to cotton or other cellulose fibers. Owing to the fact that artificial silk loses about 60 percent of its strength when wetted great care must be used in handling the yarn when dyeing, washing, or bleaching. According to Jentsch collodion silk differs from viscose and cuprate silks in taking up basic dyes directly without the aid of a mordant; this is probably explained by the fact that collodion silk contains oxycellulose. The substantive dyes, however, are principally used in the dyeing of artificial silk, a topping with basic dyes often being given in order to brighten the color. In dyeing artificial silk the temperature of the bath should not exceed 160° F. The principal defect in the dyeing of artificial silks is tendency toward uneven colors. This defect is doubtless inherent in the structure of the silk itself, the density of the fiber lacking complete homogeneity. In collodion silk this defect has been attributed to differences in the amount of residual nitrogen in the fiber, the darker shades resulting from higher percentages of nitrogen. Unevenness in colors may often be remedied by topping slightly with a basic dyestuff.

The differences experienced in the dyeing of different forms of artificial silk are of interest. The nitro or collodion silks have a strong affinity for basic dyes and unless care is used the colors will be uneven. The cuprate silks have less affinity for basic dyes, and for the production

of full shades it is necessary to mordant with tannic acid. The direct cotton dyes give the best results; sulfur dyes and vat dyes may also be used but will generally injure somewhat the luster. Viscose silk is similar to mercerised cotton in its affinity for dyestuffs. The acetate silk as at first produced could not be dyed satisfactorily as the cellulose acetate was impervious to water, but the acetate silk now produced is partially saponified and contains hydroxyl groups which give the silk a much greater affinity for dyestuffs. Cellulose acetate silk has but little affinity for the direct cotton dyes, and in order to dye with these colors special treatment must be resorted to, which consists of working the silk in a bath of caustic soda, or in some cases the caustic soda may be employed directly in the bath with the dyestuff. This treatment does not seem to have any effect on the material nor to effect the luster. The basic dyes have a direct affinity for acetate silk and no mordanting is necessary. Many of the acid dyes are also useful for acetate silk. The new series of dyestuffs discovered by Green and known as " Ionamines " have a remarkable affinity for acetate silk and may be dyed directly on that fiber.

When artificial silks are woven into fabrics with cotton or wool, or natural silk, or with a combination of these fibers, or when the artificial silks are to remain undyed for effect purposes, many difficulties are encountered on account of the different affinities of the fibers towards the dyestuffs. Each case has to be treated individually, and it is principally a matter of selecting the proper dyestuff for the purpose at hand and then properly regulating the temperature of the dyebath. To decrease the affinity of the artificial silks, especially the cuprate and viscose silks, toward substantive dyes, when interwoven with cotton, a process has been recommended consisting of a treatment of the fabric with 10 to 15 percent of tannic acid for a few hours at 150° F., and afterward, without rinsing, treating with a lukewarm bath containing 6 to 10 percent of stannous chloride (on the weight of the material). The stannous chloride is dissolved with the addition of a little hydrochloric acid.

The **acid rotting** of artificial silk is a defect to be met with in that silk prepared by Chardonnet's method from nitrated cellulose. When such artificial silk is dyed certain irregularities are frequently to be noticed, the cause of which has hitherto been generally attributed to atmospheric conditions as all tests for the presence of delcterious substances in the materials used in the dyeing process have failed to show anything which might be considered as a possibility in the production of the defects noticed. These irregularities are said to be readily corrected by immersing the dyed material in water for some time and again dyeing, but this occasions inconvenience and considerable loss of time. Heermann has shown that this acid rotting is due to the presence of unstable sulfuric acid compounds of cellulose in the fiber, and as these irregularities in dyeing

are only to be met with in the case of artificial silk from nitrated cellulose and not in the silk prepared by the viscose or cuprammonium processes, it was possible that they were due to this acid rotting of the fiber. This view has now been confirmed by the fact that extracts from unsatisfactory dyeings gave a much greater precipitate through a solution of barium hydroxide than those obtained from satisfactory dyeings. It is said that the results of acid rotting may be avoided by neutralising the fiber by treatment with an 8 to 12 percent solution of sodium acetate or sodium formate or borax. The material is then dried without washing. Furthermore, the tendency of the fiber to become weakened is removed as shown by the stability test. Artificial silk which had been heated to 140° F. with sodium acetate solution as a protective agent, then well rinsed and dried cold, was shown to be slightly improved by the treatment.

The bleaching of artificial silks should be carried out rapidly, and the best results are obtained by giving alternate baths of sodium hypochlorite and hydrochloric acid. The permanganate method of bleaching cannot be used as it weakens the fiber.

The drying of artificial silk after dyeing or bleaching should be carefully conducted; overheating (not over 110° F.) should be avoided, and the silk should be removed from the drying chamber as soon as it is properly dried.

The addition of Turkey-red oil (or Monopol oil) is frequently made to the dyebath for promoting the even distribution of the color and also for producing a soft feel on the silk. For producing a "scroop" on the fiber the silk is first passed through a soap bath, and then through a bath containing a small quantity of acetic or tartaric acid, and dried without further washing.

In **tensile strength** artificial silk shows about one-half the breaking strain of natural silk; its **elasticity** is also about one-third to one-half that of the latter, as shown in the following table:

Silk.	Breaking Strain per Denier in Grams.	Elasticity, Percent.
Natural silk	2.50	21.6
Chardonnet	0.93	8.0
Lehner	1.43	7.5
Cuprammonium	1.64	12.5
Gelatine	0.63	3.8
Viscose	1.40	9.5

Bronnert gives the following table of comparisons between the tensile strengths of modern artificial silks:

	Tensile Strength in Grams per Denier		Elasticity, Percent.
	Dry.	Wet.	
Viscose	1.3–1.8	0.4–0.8	15
Acetate	1.3–1.4	1.5	20
Cuprate	1.4	0.55	16

Dreaper reports a sample of cellulo artificial silk of 25 denier and composed of 60 filaments as having a breaking strain of 2.3 grams per denier. This is practically equivalent to natural silk in strength.

When wetted the filaments of artificial silk show a loss of 50–70 percent in tensile strength. Bronnert states that the tensile strengths of the various artificial silks in the dry state are about the same; in the wet state the cuprate silk is about 10 percent stronger.

The **luster** of artificial silk is one of its chief characteristics. In this respect it is generally superior to natural silk. Its luster, however, is somewhat metallic by reason of double refraction, and this is especially noticeable in the case of collodion silks. Owing to this property of double refraction many dyestuffs fluoresce to such an extent as to be objectionable. Acetate silk does not have the high luster of viscose or cuprate, and more nearly approaches real silk in this respect. Owing to its water-repellent nature it does not absorb moisture as readily as the other forms of artificial silk, which makes it somewhat better for weaving.

Artificial silk is more **hygroscopic** than cotton; in fact it is about equal to natural silk in this respect. The result of a large number of tests at the Elberfeld conditioning laboratory shows the hygroscopic moisture in artificial silks to vary between 9.30 and 12.99 percent, with an average of 11.3 percent. The valuation of artificial silks is now made on a basis of 11 percent of moisture, the same as natural silk.

The **density** (specific gravity) of cellulose artificial silks is about 1.56 or about 10–13, percent higher than natural silk. Acetate silk has a density of 1.25; hence it is about 6 percent less dense than real silk and about 17 percent less than the other forms of artificial silk.

The **covering power** of artificial silk is only about one-half that of natural silk, this being chiefly due to the relatively larger size of the individual filaments. Owing to differences in the structure of the cross-section of the filament, acetate silk does not have the same covering power as viscose or cuprate silk. Dreaper[1] enumerates the defects of artificial silk as compared with natural silk, as follows: (1) The size, or denier, of threads is too great; (2) the individual filaments are much larger than those of

[1] *Jour. Soc. Dyers & Col.*, 1907, p. 7.

real silk; (3) the strength and especially the elasticity are not satisfactory; (4) the loss of strength on wetting is excessive; (5) the lack of covering power reduces the value of the products.

10. Comparison of Artificial Silks.—Hassac [1] gives a comparison of several makes of artificial silk. Chardonnet's and Lehner's silks are very similar in appearance; they are more lustrous than real silk, but are stiffer, and do not possess the characteristic feel. Cellulose silk made by the ammoniacal copper oxide process is similar to the former in appearance, but its luster is even better, and it has the characteristic feel of true silk. Lehner's silk under the microscope is characterised by deep longitudinal grooves and small air-bubbles; its cross-section is highly irregular. Cuprate silk shows fine longitudinal grooves and minute transverse lines in the center of the fibers; its cross-section is regular, approaching a circle or ellipse. Hammel's gelatine silk is almost circular in outline, and is free from grooves and bubbles; in polarised light it is singly refracting, while the others are doubly so. When viewed in polarised light under the microscope collodion silk shows a bright blue color, whereas viscose and cuprammonium silks show a uniform bluish gray color.

There seems to be considerable difference in the amount of ash in the artificial silks of different origin. Mitchell and Prideaux give the following figures:

	Percent.
Collodion silk	2.23
Viscose silk	0.28
Cuprate silk	0.18

As the collodion silks always contain some nitrated compound, they give a blue color with diphenylamine and sulfuric acid. The test is carried out by dissolving a small portion of the silk sample in concentrated sulfuric acid to which has been added a trace of diphenylamine. Collodion silks will give a bright blue color immediately, whereas the other cellulose silks furnish only a slight yellow coloration. In place of diphenylamine, brucine hydrochloride may be used in the same manner, in which case the color with collodion silk is a bright red. The other cellulose silks give a yellow color. Collodion silks will usually show less than 0.2 percent of nitrogen; ordinary silk contains about 17 percent. This trace of nitrogen compound is sufficient, however, to distinguish collodion silk from viscose and cuprammonium silks.

Water causes all the artificial silks to swell, while alcohol or glycerol contracts them. In strong sulfuric acid the collodion silks swell rapidly and dissolve; cuprate silk gradually becomes thinner and dissolves; gelatine silk only dissolves on strong heating. Chromic acid dissolves all artificial silks in the cold; real silk dissolves but slowly, while cotton and other vegetable fibers are unaffected. Caustic potash does not dissolve the

[1] *Chem. Zeit.*, 1900, pp. 235, 267, 297.

collodion or cellulose silks, but both the gelatine silk and real silk are soluble on boiling. Schweitzer's reagent dissolves collodion and other cellulose silks; whereas gelatine silk is insoluble but stains the liquid a bright violet. Alkaline copper-glycerol solution at 80° C. dissolves real silk immediately. Tussah and gelatine silks dissolve when boiled for one minute; the other silks are not affected. Iodine solution colors artificial silks an intense red, which changes to a transient pale blue on washing with water in the case of collodion silks, though cellulose silk does not show this blue color. Iodine and sulfuric acid stain true silk a yellow color, gelatine silk brown, while the cellulose silks are colored blue.

Cuprate silk is distinguished from collodion silk by its very low copper index. The cellulose of which cuprate silk is composed appears to be of a higher degree of hydration than that in viscose silk, as evidenced by the greater solidity of this latter variety in the moist condition. Cuprate silk always retains traces of copper, giving the fiber a milky or bluish appearance; when treated with ammonium sulfide it gives a grayish color. Cuprate silk is also somewhat less limpid and brilliant than viscose silk. According to Bronnert, viscose and cuprate silks may be recognised by applying a few drops of strong sulfuric acid to the fibers; cuprate silk becomes yellow, and develops a straw-colored solution which increases in intensity to a brown color; viscose silk, on the other hand, will immediately give a reddish brown color.

Massot gives the average thickness of the filaments of different varieties of artificial silk as follows:

	Microns.
Chardonnet silk	28.8
Lehner silk	35.4
Cuprate silk	31.4
Viscose silk	30.5
Genuine silk	15.0

Comparison of Different Artificial Silks with Real Silk (Hassac)

Silk.	Moisture.		Sp. Gr.	Fibers to Sq. Mm.		Tens. Strength, Kilo. per Sq. Mm.		Elasticity, Percent.
	Air-dry, Percent.	Saturated, Percent.		Wet.	Dry.	Wet.	Dry.	
Real silk	8.71	20 11	1.36	9710	9710	37.0	37.0	21.6
Chardonnet	11.11	27.46	1.52	640	1135	2.2	12.0	8.0
" (Walston)	11.32	28.94	1.53	683	1620	1.0	22.3	7.9
Lehner	10.45	26.45	1.51	413	1180	1.5	16.9	7.5
Cuprate	9.20	23.08	1.50	742	1550	3.2	19.1	12.5
Gelatine	13.98	45.56	1.37	265	945	0.0	6.6	3.8

Silbermann gives the following figures for the elasticity of different silks:

	Percent.
Real silk	17.2
Tussah silk	18.0
Chardonnet silk	11.6
Vivier silk	9.6

It is claimed that the elasticity of the Thiele cuprate silk is practically equal to that of real silk.

According to Süvern the amount of moisture in air-dry silks is as follows:

	Percent.
China raw silk	7.97
Tussah silk	8.26
Chardonnet silk	10.37–11.17
Lehner silk	10.71
Cuprate	10.04
Viscose silk	11.44
Gelatine silk	13.02

Strehlenert and Westergren give the following figures for the tensile strengths of various natural and artificial silks, the figures indicating the breaking strains in kilograms per square millimeter section:

Natural Silks

	Dry.	Wet.
Chinese silk	53.2	46.7
French raw silk	50.4	40.9
French silk, boiled off	25.5	13.6
" dyed red and weighted	20.0	15.6
" blue-black, weighted 110 percent	12.1	8.0
" black, weighted 140 percent	7.9	6.3
" black, weighted 500 percent	2.2	

Artificial Silks

	Dry.	Wet.
Chardonnet's collodion, undyed	14.7	1.7
Lenher's collodion, undyed	17.1	4.3
Strehlenert's collodion, undyed	15.9	3.6
Cuprate, undyed	19.1	3.2
Viscose silk, early samples	11.4	3.5
" latest samples	21.5	
Cotton yarn (for comparison)	11.5	18.6

Cross and Bevan[1] give the following data regarding the strength of artificial silks:

	Artificial Silks.	True Silk Boiled-off.
Breaking strain per unit denier (grams).....	1.0–1.4	2.0–2.5
Stretch under breaking strain (percent)....	13–17	15–25
True elasticity (percent).....	4–5	4–5

In contradistinction to the general opinion, artificial silk withstands wear and rubbing quite well, and fabrics of artificial silk if properly handled will stand laundering as well as those of cotton. Artificial silk linings are said to be better than those of Italian cloth, as the surface is so smooth that it slips easily and puts the burden of wear on the other fabric. Artificial silk used in hosiery stands up under wear about as well as cotton.

The commercial sizes in which artificial silk is generally employed is from 110 to 150 denier for weaving and braiding; coarser numbers are used for passementerie articles, etc. By the Thiele process of manufacture artificial silk threads of 40 denier and even less may be produced, each thread consisting of 80 filaments. In this variety of silk the single silk filament is finer than that of natural silk ($\frac{1}{2}$ to 1 denier), and this gives the thread greater elasticity and softness. In other varieties of artificial silk the size of the individual filaments averages 5 to 8 denier, or about twice that of the natural silk fiber. Owing to its structure it is also claimed that Thiele's silk has much greater strength than other varieties of artificial silk; its strength, in fact, being only 20 percent less than that of real silk.

The covering power of artificial silk is dependent chiefly upon the surface possessed by a given weight of thread, and again upon area of the cross-section of the individual filament of the thread. As regards the size of the filaments, the cover increases as the size decreases in proportion to the diameter of the filaments, so that of two threads of the same diameter, one with eighteen filaments the other with thirty, the latter would have about 30 percent more cover than the former. The weight of the filament, however, is not the only factor, nor does the specific gravity of the various silks vary sufficiently to be taken into account, but the shape of the cross-section of the filaments is of vital importance in this connection. A filament with a circular section has less covering power than a filament of any other shape, and the greater the departure from the round section the more effective becomes the thread; also with increased surface for the reflection of light, other things being equal, there is a correspondingly improved luster. The cross-sections of artificial threads vary to a large

[1] *Jour. Soc. Chem. Ind.*, 1908, p. 1189.

extent and can be varied to a wide range, the controlling factors being the composition of the cellulose solution and the strength of the decomposing bath; this is in the case of silk of the viscose or cuprate type. Cellulose acetate silk being spun into free air can have a like control by the speed at which it is dried, or, in other words, the rate at which the acetone is evaporated.

With regard to cost of manufacture there is little doubt that viscose silk is the cheapest, with cuprate silk next, and collodion and acetate silks are the most expensive.

11. Microscopy of Artificial Silks.—When viewed under the microscope artificial silk presents mostly a smooth, structureless appearance, resembling that of a transparent glass rod. The appearance is quite different from that of the other textile fibers, and usually the cross-sections of the fibers are quite characteristic. The various kinds of artificial silk may usually be distinguished by their microscopic characteristics.

Herzog gives the following summary of the microscopical properties of artificial silks:

1. (*a*) Between crossed Nicol prisms marked brightening of the optical field.....See 2
   (*b*) Between crossed Nicol prisms little or no brightening of the optical field.....See 3
2. (*a*) Stained with Congo Red strong dichroism.....See 4
   (*b*) Stained with Congo Red no dichroism.....See 5
3. (*a*) After insertion of gypsum plate red appears
   with +45° addition color.
   with −45° subtraction color.....See 6
   (*b*) As in (*a*) reversed after insertion of mica plate the fiber appears between parallel Nicols
   with +45° white.
   with −45° brown.
   Mounted in citron oil, appears almost invisible; ultramicroscopic granular structure very weak.....*Acetate Silk*
4. (*a*) Polarisation colors luminous but changing, arranged in more or less parallel striations; ultramicroscopic structure granular but rather indistinct.....*Collodion Silk*
   (*b*) As in (*a*) but colors not so pronounced and the parallel striations are not so prominent; ultramicroscopic appearance shows granulations quite marked.....*Viscose Silk*
   (*c*) Fiber mass shows a single brownish orange color; between parallel Nicols a uniform grayish blue; with ultramicroscope very marked granulations.....*Cuprate Silk*
5. (*a*) Polarisation colors uniform bluish or yellowish, seldom reddish violet; with ultramicroscope strongly marked parallel structure.....*True Silk*
   (*b*) Polarisation colors various and rapidly alternating showing broad band-like fibrils; with ultramicroscope parallel structure very apparent.....*Tussah Silk*

6. (*a*) Double refraction shown without use of gypsum plate, simply by stretching or squeezing the fiber; with Congo Red not dichroic; mounted in clove oil almost invisible; with ultramicroscope no structure shown, only impurities are seen..... *Gelatine Silk*

(*b*) Double refraction quite weak, but may be observed between crossed Nicols and without the use of gypsum plate; stained with Congo Red not dichroic; natural color yellowish to brownish yellow..... *Mussel Silk*

According to Cross, the contour of the silk filament is quite distinctive with the process of manufacture. The contour is governed by the manner in which the original cylinder of cellulose solution contracts during the operations of coagulation and dehydration. Three broad classes of section may be distinguished:

(1) The whole filament contracts slowly and evenly, giving a fairly regular section, corresponding to cuprate silk (also the early form of viscose silk (Fig. 278).

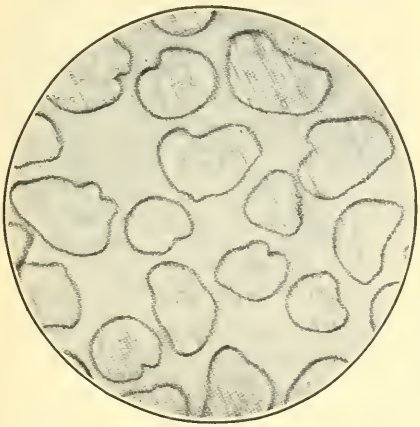


Fig. 278.—Cross-sections of Cuprate Silk. (Cross.)

Fig. 279.—Cross-sections of Collodion Silk. (Cross.)

(2) The outline remains smooth while the walls contract inward, giving an irregular shape with a smooth surface, corresponding to collodion and acetate silks (Figs. 279 and 280).

(3) The walls become corrugated in an attempt to adjust the original circumference to a diminished sectional area, corresponding to modern viscose silk (Fig. 281).

A new method for examining the cross-section of artificial silk fibers is described by Herzog [1] which, it is claimed, enables even an inexperienced

[1] *Deutsche Faserstoffe*, 1921, p. 52.

observer to make this examination in about a minute, as it avoids the necessity of preparing and embedding fine sections. The bundle of fibers to be examined is treated with 4 percent collodion, to prevent spreading of the fibers, and then cut across with a sharp knife against a glass surface. The section is placed against a side of a right-angled prism, the hypotenuse of which is silvered, in the direction of the light. The prism acts as a total reflector, and the section is examined microscopically through the third face of the prism.

12. Ultramicroscopic Studies of Artificial Silk.—By the ordinary processes of microscopy it is not possible to distinguish structural elements of a smaller size than 0.2 micron. During rather recent years, however, the study of colloids has developed a method of examination known as ultramicroscopy and a number of investigators have applied this technique

FIG. 280.—Cross-sections of Acetate Silk. (Cross.)

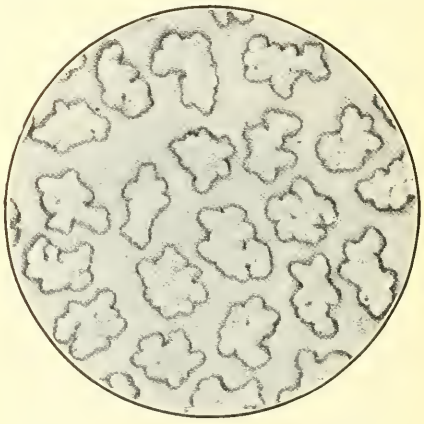


FIG. 281.—Cross-sections of Modern Viscose Silk. (Cross.)

to the examination of textile fibers and more particularly to artificial silks (Siedentopf, Schneider and Kunzl, Gaidukov, and Herzog).[1] By the use of the ultramicroscope (Fig. 282) magnifications up to 2500 can be obtained and considerable light is thrown on the minute inner structure of many bodies. When examined by ultramicroscopic methods the artificial silks exhibit certain well-defined differences among themselves and also from such other fibers as true silk, tussah silk, and cotton. Cuprate, viscose, and collodion silks show a granulated structure, but these granules are different in size and form (Figs. 283, 284, and 285). The results with acetate silk are not very satisfactory, but as this variety of silk can be so

[1] Schneider and Kunzl, "Spinnfasern und Färbungen im Ultramikroskop," *Zeitschr. f. wiss. Mikrosk.*, vol. 24, No. 4; Gaidukov, "Ueber die Anwendung des Ultramikroskopes in der Textil- und Farbstoff-Industrie," *Zeitschr. f. ang. Chemie*, 1908.

readily distinguished by other more obvious means it does not come into consideration here. Gelatine silk is optically clear and gives no results with the ultramicroscope, but as this silk is of little or no commercial importance at the present time it may also be left out of consideration. True silk and tussah silk both show a distinct parallel structure with the ultramicroscope (Figs. 286 and 287) while cotton shows an apparently laminated structure (Fig. 288).

13. Uses of Various Cellulose Solutions.—Silklike filaments may be obtained from a solution of cellulose in zinc chloride.[1] The liquid may be easily spun, but the thread which is formed is too weak to be employed as a substitute for silk. The solution is principally used for the manu-

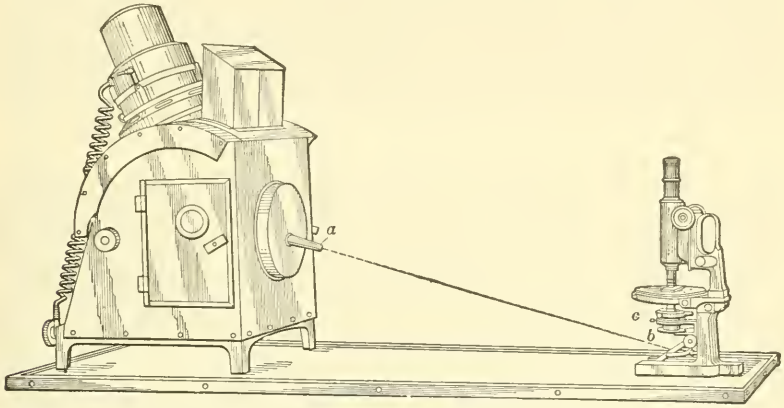


FIG. 282.—Apparatus for the Ultramicroscopic Examination of Fibers.

facture of filaments for incandescent electric lamps. A better solution is obtained by using alkali-cellulose in place of cellulose (Bronnert).

Foltzer points out the fact (*Textile Manufacturer*) that ordinary cellulose is only slightly soluble in cold zinc chloride, in which it becomes a gelatinous substance; a real solution is obtained only with a high temperature. Without doubt the zinc chloride, by its hydrating action, produces depolymerisation of the cellulose, such that the substance precipitated possesses only in a slight degree the characteristic properties of cellulose. Wynne and Powell have tried to replace the zinc chloride by a mixture of zinc chloride and aluminium chloride. It is possible that depolymerisation may be retarded somewhat in this manner; but Wynne and Powell, as well as Dreaper and Thomson—who have also proposed to employ cellulose dissolved in zinc chloride to produce a textile thread—have been able to obtain this solution only by raising the zinc chloride to a high temperature.

[1] Dreaper and Thomson (*Brit. Pat.* 17,901 of 1898). The solution of cellulose in zinc chloride is forced through jets into alcohol or acetone, which coagulates the cellulose.

However, it has been stated that during these processes the molecular constitution of the cellulose is changed, and the threads thus formed are exceedingly weak. In an American patent, Bronnert describes a method which, so far as we know, has not yet passed beyond the experimental state; according to this method, it would be possible to obtain a strong thread by subjecting the cellulose to preliminary processes before dissolving

Fig. 283.—Structure of Cuprate Silk under Ultramicroscope.

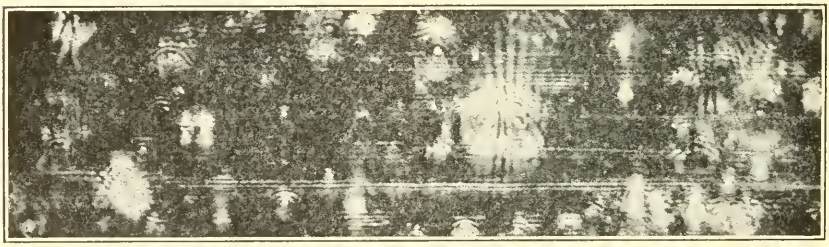


Fig. 284.—Structure of Viscose Silk under Ultramicroscope.

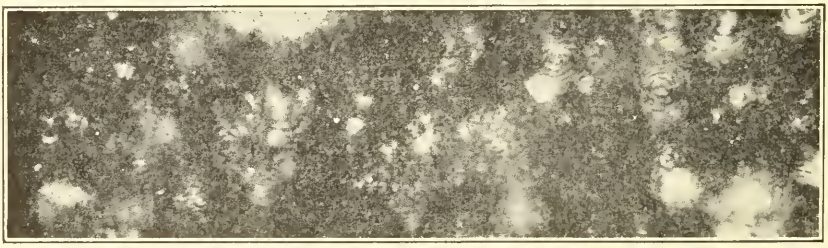


Fig. 285.—Structure of Collodion Silk under Ultramicroscope.

it in zinc chloride, just as was done for the cellulose dissolved in an ammoniacal solution of copper oxide.

The most advantageous method consists in transforming the scoured and bleached cellulose into soda cellulose by immersing it in a cold bath of concentrated caustic soda, then decomposing the soda cellulose with water, and finally in dissolving the cellulose thus obtained in a concentrated solution of zinc chloride. The solutions prepared in this manner

must be kept in tanks and at a low temperature, so as to prevent any decomposition which would be detrimental to good spinning, and might even make this operation impossible. A new process, and one which

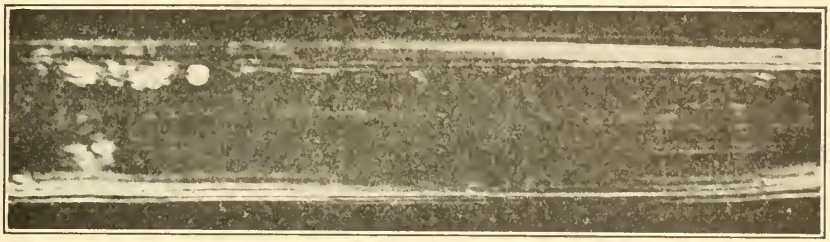


FIG. 286.—Structure of True Silk under Ultramicroscope.

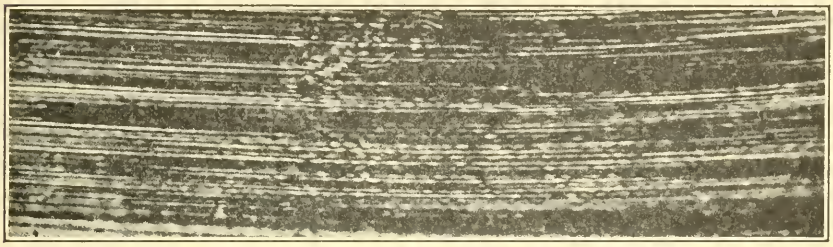


FIG. 287.—Structure of Tussah Silk under Ultramicroscope.

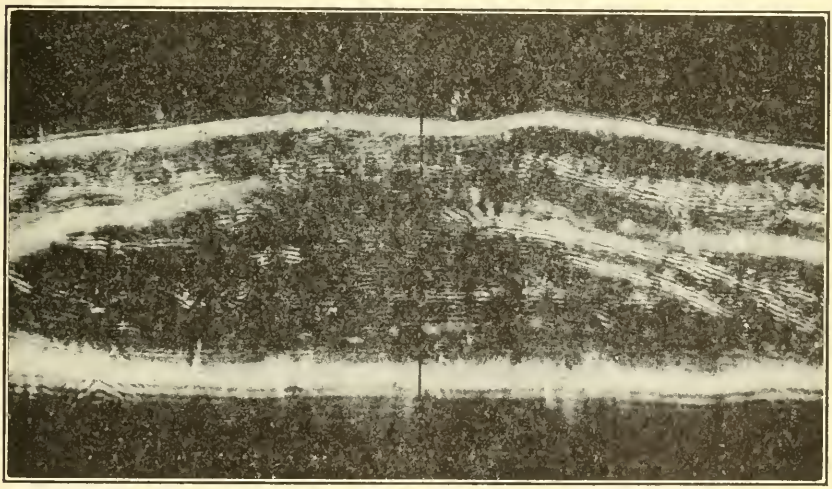


FIG. 288.—Structure of Cotton Fiber under Ultramicroscope. (×1400.)

appears to have a future, is that of the alkali cellulose by Beltzer, of Paris. When wood-pulp is introduced uniformly into a caustic soda lye of 10° Bé. and at a temperature of 32° to 41° F. hydration takes place; an almost

complete solution is obtained only when the temperature is lowered to 14° F. With these solutions of alkali cellulose the inventor has been able to produce artificial silk, pellicles, etc. Again, Beltzer observes that, like solutions of caustic soda, sulfuric acid, phosphoric acid, etc., when employed at the proper concentration, mercerise or hydrate cellulose. Sulfuric acid, for example, at 49° to 55° Bé., transforms cellulose into a parchment-like substance which dissolves in the cold and forms a viscous, homogeneous, and transparent mass. This solution is termed amyloid because of its resemblance to amidon (starch). The same result is obtained by treating cotton cellulose or wood pulp with zinc chloride, or with phosphoric acid at a certain concentration. The action of these agents on cellulose has been known for a considerable time; but it has been left for J. G. Beltzer to make experiments at low temperatures of 32° to 14° F., by which he has been able to prevent hydrolysis and destruction of the cellulose. As soon as a gelatinous solution of hydrated cellulose is obtained at this low temperature, the solution is diluted with cold water, preferably with ice, to avoid too great a rise in temperature. It then forms a precipitate of hydrated cellulose, which is washed in water, or in a bath which is slightly alkaline, to remove the acid; after a final washing with cold water a pure hydrated cellulose is obtained which dissolves completely in caustic-soda lye.

14. Artificial Horsehair.—It has already been mentioned that artificial horsehair has been prepared in a manner similar to artificial silk by spinning coarse filaments (300–400 denier) of the cellulose solutions. Threads of silk, cotton, and linen are also coated with a layer of collodion or other cellulose solution to form lustrous silk-like yarns.[1] Silk fish-lines coated in this manner with pyroxylin and dyed a light green gives a thread which is impermeable to water, has a tendency to float, and is practically invisible beneath water.

Crinol is the name given to an artificial hair prepared from cuprammonium cellulose; *meteor* is a name for a similar article.

15. Staple Fiber and Fibro.—During the recent war there was developed an artificial silk product in Germany known as "staple fiber." Very fine artificial silk fibers are twisted into thick threads and these are cut into lengths of 4 to 5 cm.; the fine fibers separate out again and are spun into yarns, sometimes alone, but mostly in connection with wool or other fibers. Yarns of staple fiber were used very largely for apparel fabrics. Fibro is an artificial silk product of British manufacture; it consists of short lengths of the fibers and is employed for the spinning of specialty yarns and fabrics requiring a high degree of luster. It is being

[1] A close imitation to natural black horsehair is prepared by coating a 50's six-cord black thread with a suitable pyroxylin solution. The coated thread, while still black has a peculiar superficial transparency which is so noticeable in the natural hair.

produced in increasing amounts as a self fiber and is not used as a substitute for wool.

16. Ribbon Straw from Artificial Silk.—This is made by forming the artificial silk solution into a thin ribbon instead of a fine filament. The ribbons are generally 1 to 5 mm. in width and about 0.02 mm. in thickness. The cellulose solution is projected through a slit-shaped aperture into the coagulating bath. The product is highly lustrous, dyes readily and is extensively used in hat making and fancy work.

17. Minor Uses of Cellulose Solutions.—Foltzer (*Textile Manufacturer*) calls attention to other uses of viscose independent to its transformation into artificial silk, as follows:

(I) Decorative painting with cellulose as base: The collective power of dissolved cellulose (viscose), which is capable of retaining nearly twenty times its weight of mineral powder, is very suitable for forming the base of a paint which, due to the stability of cellulose, resists successfully atmospheric influences. This paint adheres perfectly to plaster even before the latter is perfectly dry; to wood, cements, and even to felt and bitumen boards. It is incombustible, and yields a smooth and homogeneous surface which can be washed with soda a few days after the paint has been applied.

(II) Paper for art impressions: The characteristic features of paints with cellulose as base render them particularly suitable for the manufacture of paper for art impressions; a surface of remarkable smoothness and exceptional softness can thus be obtained, upon which it is possible to engrave figures possessing that finish which is typical of high-class reproductions.

(III) Lining or covering for fabrics: Employed pure or slightly loaded, viscose forms on the surface of fabrics a very homogeneous layer, which is insoluble in water, and which resists effectively the action of acids and alkalies; transparent viscose can be used on cloth for shades, and opaque viscose used on cloth for waterproof bed covers and for bookbinding. When prepared for the latter purpose it forms a surface which is admirably adapted for engraving and goffering.

(IV) Viscose—india rubber: Viscose mixed with india rubber is a cheaper substance than pure rubber, and may be used for practically all purposes for which rubber has formerly been used—e.g., waterproof garments, tubes, etc. In combination with viscose, india rubber resists atmospheric action better, and its flexibility is entirely preserved.

(V) Embossing and finishing effects on fabrics and threads: Viscose can be used very economically as a layer for receiving color impressions, especially white. On fabrics or threads it forms a cellulose finish which is unaffected by washing. In dyeing, viscose forms a mordant for certain coloring matters, thus effecting an economic use of dyewares.

(VI) Papers, cardboard: Employed in the manufacture of cards and of stout paper for packing purposes, viscose adds additional strength, which varies from 30 to 100 percent according to the compositions of the mixture. In a similar way viscose leather papers or mock-leathers have been made.

(VII) Compressed viscoid: In virtue of its adherent qualities viscose yields compact substances of every form. This product is an excellent insulating substance for heat and electricity, and is known by the name "Viscoid."

(VIII) Various industrial substances: Transparent films of all colors for various purposes have been made from viscose; packing papers for soap and similar fatty substances; transparencies for use as imitation stained glass windows and other purposes; colored balloons or globes for electric-light illumination; thick and strong films for replacing celluloid in numerous ways.

18. Lace and Tulle from Cellulose Solutions.—A product very closely related to artificial silk, though not spun into a fiber or filament, is the artificial lace made from solutions of cellulose, the cuprammonium solution being usually employed.

According to J. Foltzer, the idea of manufacturing tulle and lace without having recourse to spinning and weaving was first developed in 1899 by Adam Millar, of Glasgow, who constructed an apparatus for this purpose. Solutions of cellulose or other viscous substances were forced through capillary tubes on to an endless cloth. As the viscous liquid flowed through the capillary tube it hardened. The movement of the distributors was adjusted so that the outer edges of each sinuous band joined the outer edges of the neighboring sinuous bands at regular intervals, became attached, and thus formed an artificial tulle with regular meshes. According to the nature of the cellulose solution or the viscous liquid employed, it was necessary to coagulate the threads on the endless cloth, or to dry them by means of steam. This tulle could then be made waterproof, or receive other supplementary treatment. By varying the speed of the endless cloth and the to-and-fro movement of the capillary tube it is possible to vary the character of the meshes.

In 1901 another patent was taken out by Joseph Mugnier, of Lyons, for the manufacture of artificial tulle. This consisted of the preparation of a special solution, to which the inventor added glycerol and other products, which augmented the viscosity of the solution and added to the flexibility and strength of the product. Still another idea is that due to Emile Duinat, in 1906, in his French patent No. 368,398. The solution of cellulose is forced through a rectangular slot, in which rise and fall one or more sets of grips in the form of teeth; these teeth divide or interrupt the continuous flow of the solution, and the latter consequently

emerges in the form of fine bands or ribbons, or of thick threads, and thus produces a kind of artificial tulle.

The simplest idea, however, as well as the most practicable, for the manufacture of this artificial tulle is that invented by Marius Ratignier, Director of la Société H. Pervilhac et Cie., Lyons. The process of Ratignier-Pervilhac gives a continuous arrangement which enables one to manufacture indefinite lengths of this new product.

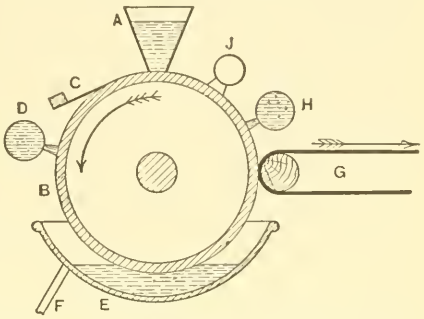


Fig. 289.—Apparatus for Making Artificial Tulle.

The apparatus is shown in Fig. 289. The solution of cellulose in the correct degree of viscosity is in the tank (*A*) and flows uniformly on to the engraved cylinder (*B*) which rotates in the direction of the arrow. All the parts which form the design are thus filled with the solution, and a thin layer may also be deposited on the remaining or plain parts of the cylinder. This thin layer is removed by the knife or scraper (*C*). A coagulating liquid is forced from the pipe (*D*) and impinges against the cylinder in its full width; the surplus liquid falls into the bath (*E*) and thus serves to complete the coagulation, while the bath is kept at a constant depth by means of the overflow pipe (*F*). The coagulating liquid is caught as it emerges from the pipe and used again. The artificial silk product is removed from the cylinder by an endless cloth (*G*) which travels in the direction indicated, and the tulle, lace, or the like is finally wound on to a suitable drum. A jet of water from the pipe (*H*) flows over the full width of the engraved cylinder and thus removes the chemical substances, while the recesses in the cylinder are dried by a current of warm air from (*J*). The process is thus continuous, and any suitable design may be engraved on the metal cylinder. An enlarged view of the meshes of this artificial tulle is shown in Fig. 290.

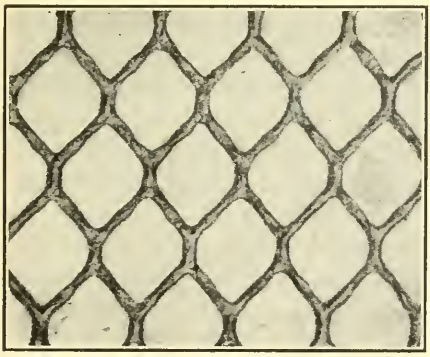


Fig. 290.—Artificial Tulle Showing Formation of Meshes.

A great quantity of very beautiful artificial tulle is now made. At first sight it is difficult to distinguish it from ordinary tulle. The artificial

product is naturally less pliable than tulle made from ordinary textile threads, and it is also weaker; it has the luster of artificial silk, and may be metallised or waterproofed. The product has been employed mostly for millinery purposes. It has been manufactured largely by la Cie. française des Applications de la Cellulose, at Fresnoy-le-Grande, and is also manufactured in the United States.

In the Swiss patent No. 57,951 (1911), la Cie. des Applications de la Cellulose gives a formula for a special solution of cellulose for the manufacture of artificial tulle. The method of preparation is as follows: 30 kilos. of cleaned and partially bleached cotton is pulverised in a suitable machine until all the fibers of cotton are reduced to powder. To this pulverised cotton is added a sufficient quantity of water to make up the total volume of cotton and water to 3000 liters. Then 60 kilos. of crystallised copper sulfate is dissolved in 300 to 400 liters of water, and to this solution is added, little by little, 40 liters of caustic soda. The two solutions are then mixed, and the cellulose absorbs, almost immediately, all the hydroxide of copper. The surplus liquid is now removed by a hydroextractor, by pressure, or by filtration, and the residue of cellulose charged with hydroxide of copper is cut up into slices. This substance is then dissolved in 100 liters of ammonia at 28° Bé. It is then left to work up for fifteen to twenty minutes, and then allowed to stand for twenty-five hours. Finally, the mixer is restarted, and, with the object of completing the solution, about 0.6 liter of caustic soda at 38° Bé. is added for each kilogram of dissolved cellulose. The preparation of this solution of cellulose is conducted at the ordinary temperature.

In the British patent No. 11,714 (1911) la Cie. des Applications de la Cellulose describes a process of coagulating artificial tulle in a caustic soda bath. When cellulose dissolved in ammoniacal copper oxide is precipitated in an acid bath the acid removes almost immediately practically all the copper from the precipitated product, and leaves the substance nearly white; whereas, if caustic soda or caustic potash is used for precipitation, the copper is only partially removed, and the product thread or tulle, is blue. In order to remove the rest of the copper, it is necessary to pass the product through a dilute acid. Again, in employing alkalies for coagulation, the coagulating liquids themselves take on a deep blue color in consequence of the presence of part of the copper which has been removed during the coagulation.

In the manufacture of artificial silk this deep color formation is a disadvantage, for it prevents, to some extent, the operatives from seeing the thread clearly, and from controlling successfully the formation of the thread—a disadvantage which does not exist when coagulation is performed in acid baths. Such a disadvantage is increased in connection with the manufacture of artificial tulle, for it is necessary to see continually

if the tulle is properly made, and to make sure that no meshes remain in the engraved parts of the cylinder. The above French company has been able to prevent the deposition of copper in the liquid by adding to the alkaline coagulating bath 10 grams of commercial white arsenious acid (As_2O_3) per liter of caustic soda of 30 percent, and keeping the mixture at a temperature of 140° to 149° F. The presence of the arsenious acid prevents the elimination of copper, and the soda bath remains clear and uncolored even after having been used for a month. On the other hand, the threads or tulle contain all the copper, and are therefore of an intense blue color. The threads are wound on spools and the tulle on cylinders, then washed to remove the alkali, and finally the product is readily freed from copper in dilute sulfuric acid at 5° Bé. without any precipitate of cupro-arsenious products. The products obtained in this way are, when dry, distinguished by their brilliancy, pliability, and elasticity.

Another unique process for the manufacture of artificial tulle and lace is that described by Joseph Foltzer (Swiss patent No. 69,514, October, 1913): Method of making artificial textile products from solutions of cellulose or plastic substances, nitro-cellulose, viscose, cellulose of acetyl, and the like; casein, fibrine, maizine, and the like; or from rubber. These solutions or substances are applied as thin layers, corresponding to the thickness of the desired body, by means of a spreading apparatus which deposits the substance on to a cylinder, an endless cloth, or some such suitable receptable. The substance applied to the cylinder is stemmed in front of an engraved pressure or goffering roll which is placed either close to or at a short distance from the laying-on or spreading apparatus. This roll, which is positively driven and which presses against the cylinder, stamps out the viscous mass in forms which coincide with the engraving on the goffering roll.

The work may be performed by the methods illustrated in Fig. 291. The solution of cellulose or viscous mass contained in the spreading apparatus (*A*) escapes on to the cylinder (*D*) as a layer which corresponds in thickness to the depth of the engraved parts in the goffering roll (*B*). The rollers rotate as indicated, and two wings or blades (*E*) which connect the laying-on apparatus to the roll prevent the substance from escaping at the sides. The solution is fed toward the grip of the roll and the cylinder, but cannot proceed farther as a body. The engraved parts on the roll representing the design for tulle or other textile texture, become filled with the solution in virtue of the pressure, and by this time the substance is partially set so that it may be conveyed farther upon the circumference of the cylinder and immersed in a hardening liquid contained in the tank (*C*). Soon after the formed fabric emerges from the bath it is detached from the cylinder by means of the rollers (*F*). It is then guided

by rollers (*G*, *H*, *J*, and *K*) into and out of the three vats (*L*, *M*, and *N*) which contain suitable liquids for the further treatment of the product, as, for example, precipitation, acidification, and cleansing. The finished fabric is finally wound upon a reel (*P*).

It has been found in practice that the stamped or pressed-out artificial products adhere very frequently to the engraved parts of the pressure roll from which they can be detached only with difficulty. This is particularly the case when thick embroidery is being made. To prevent this annoying feature, the roll is sprayed with a liquid at (*Q*) which precipitates the solution, while the excess liquid is removed by the stripping-knives (*R*). The adhering of the substance to the engraved parts of the roller might also be prevented by heating the roller to that temperature which causes

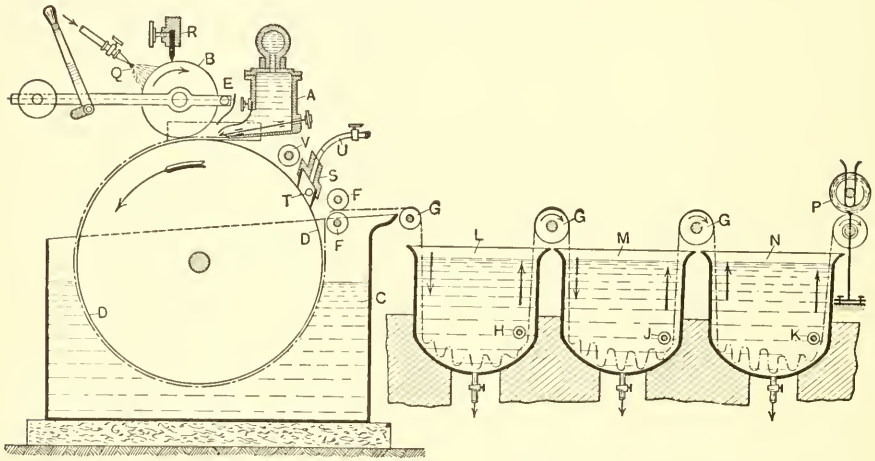


Fig. 291.—Installation for Making Artificial Lace. (Foltzer.)

a superficial coagulation. The outer surface of the cylinder must also be cleaned very carefully between the rollers and the outlet of the spreading apparatus. For this purpose is provided the receptable (*S*), the lateral outlet pipe (*F*), and the pipe (*U*), through which may pass a cleansing liquid. As is indicated, the lateral walls of the receptable act as stripping-knives, while a heated drum (*V*) dries the surface of the cylinder. Special effects may be obtained if fine fibrous powder, either of one color or of different colors, be mixed with the solution of cellulose, or if such powder be sprinkled on the roller to enable it to adhere to the surface of the substance when the latter is stamped out. In order to impart a suitable surface to the products, liquid gum, tallow, fine metallic powder, and the like may be used.

19. Animalised Cotton.—Cotton may be "animalised"—that is, given the dyeing properties possessed by animal fibers—in a variety of

ways. The material may be impregnated with albumen and afterward steamed; this method is employed to some extent in printing, being used chiefly in connection with the direct cotton colors to prevent their bleeding. A solution of casein may also be used instead of albumen, with similar results. The same property may also be imparted to cotton by treatment with tannic acid and gelatine or lanuginic acid (solution of wool in caustic alkali), but with doubtful results; though Knecht describes a method which is said to give satisfaction, the cotton being impregnated with a solution of lanuginic acid and allowed to dry in the presence of formaldehyde, when the fiber becomes coated with an insoluble film possessing a remarkable affinity for the substantive dyes. Vignon claims that by treating cotton under pressure with ammonia in presence of zinc chloride or calcium chloride, the fiber acquires an increased affinity for the basic and acid dyestuffs. His results, however, have not been confirmed.

A silklike appearance may also be given to vegetable fibers by treatment with a solution of silk (fibroin) in some suitable solvent, such as hydrochloric, phosphoric, or sulfuric acid, or cuprammonium, etc. The silk employed is made up of scraps and waste which would otherwise be useless. Better results are obtained if the cotton material be treated with a metallic or tannic acid mordant before immersion in the silk solution. It should afterward be calendered and polished in order to obtain a glossy appearance.

20. Statistical.—The production of artificial silk of different varieties in the United States for the year 1921 was about 20,000,000 lbs. The total annual production of artificial silk in the entire world for 1914 was only 26,000,000 lbs., so it may be seen that this industry is expanding very rapidly.[1] The great bulk of the American production went into domestic consumption, and besides an appreciable amount was imported (nearly 4,000,000 lbs.). The field for artificial silk is continually growing and is by no means exhausted as yet. It must not be considered simply as a substitute or competitor for real silk, but the artificial fiber has a distinct field of usefulness for itself. It is adapted to the manufacture of a wide variety of apparel and ornamental fabrics and in this connection should stand on its own basis as a fiber.

[1] The following table shows the estimated amounts of the different varieties of artificial silks produced in the world in the year 1908:

	Pounds.
Collodion silk	4,125,000
Cuprate silk	3,080,000
Viscose silk	1,089,000
Total	8,294,000

At the present time the relative order of these varieties is reversed, the amount of viscose silk produced being overwhelmingly greater than the others.

There are a number of companies manufacturing artificial silk in the United States, of which the following are the more important: The American Viscose Company with plants at Marcus Hook, Lewistown, and Roanoke; the combined plants have a capacity of about 28,000,000 lbs. per year. The Du Pont Fibersilk Co., with a plant at Buffalo, also making viscose silk with a capacity of 1,500,000 lbs. per year. The Tubize Artificial Silk Co. of America, with a plant at Hopewell making pyroxylin silk with a capacity of about 4,500,000 lbs. per year. The Industrial Fiber Co., of Cleveland, making cuprate silk with a capacity of 1,000,000 lbs. per year. The Lustron Company of Boston, making acetate silk. The American Cellulose and Chemical Company with a plant at Cumberland, making acetate silk with a capacity of 3,000,000 lbs. per year. Most of the artificial silk spun is of 150 denier size, though the last-named company is equipped to spun as fine as 45 denier. The Tubize Company spins from 110 to 180 denier silk.[1]

Artificial silk has supplemented rather than directly competed with natural silk, though in certain lines of fabrics, such as cheap hosiery and underwear and sweaters and the like, it may be said to be a substitute for silk. The price relations of the two fibers are somewhat interesting. Unbleached viscose silk yarn, Grade A, 150 denier, in 1913 sold for $1.80 per pound and in October, 1921, for $2.75 per pound. Raw silk, Shinsiu No. 1 in 1913 sold for $3.47 per pound and in 1921 for $6.05 per pound.

[1] The following table of Exports of Artificial Silk Hosiery from the United States is interesting from the statistical point of view:

Country.	1918.	1919.	1920.	1921.
		(Dozen Pairs.)		
Belgium	.....	13,113	9,991	13,714
Denmark	1,000	129,879	66,193	16,352
France	150	3,231	20,734	5,376
Italy	15,675	2,300	16,015	14,611
Spain	.....	4,755	7,700	4,225
Switzerland	.....	8,470	3,876	3,409
United Kingdom	231,500	459,552	577,885	294,341
Canada	69,650	57,905	62,114	12,034
Mexico	6,819	8,368	7,755	11,528
Cuba	16,459	33,829	31,320	29,914
Argentina	28,829	136,549	90,686	68,610
Brazil	438	1,789	1,888	1,466
Chile	2,792	7,949	5,136	8,098
Uruguay	1,500	11,834	18,013	12,582
British East Indies	837	1,814	3,841	9,822
Australia	69,510	255,810	75,616	44,742
New Zealand	14,469	51,474	10,678	7,731
British South Africa	18,426	61,773	13,908	9,629
Other countries	22,883	67,217	82,905	90,610
Total	500,937	1,317,611	1,106,254	658,794

The manufacture of artificial silk has also the opportunity of developing other products with the same equipment and raw material. By increasing the size of the aperture through which the cellulose solution is forced, artificial hair, of value in the manufacture of hats, upholstery materials and fancy goods, may be produced. By changing the shape of the aperture to a horizontal slit, it is possible to make artificial straw, or by widening the slit further, strips of artificial leather or cloth, films, ribbons, or thin transparent sheets such as are used in facing envelopes and wrapping candies. A method has been devised in which net and simple forms of lace are produced in one operation, by passing the solution into engraved lines on a revolving cylinder, from which the finished product is continuously peeled as it issues from the fixing bath. Further progress in this direction may be confidently expected as the possibilities of cellulose are as yet far from exhausted.[1]

At no time during the past decade, nor even at present, has the world supply of artificial silk been equal to the demand. The following table (*Commerce Reports*) shows the imports of artificial silk yarns into the United States for the past ten years:[2]

Year.	Pounds.	Value.	Year.	Pounds.	Value.
1912	1,457,544	$1,757,989	1917	506,613	$1,262,580
1913	1,942,177	2,385,350	1918	293,421	741,822
1914	2,759,306	3,461,039	1919	298,122	825,117
1915	2,780,063	3,302,599	1920	2,251,927	8,690,952
1916	2,041,193	2,924,458	1921	2,613,024	

[1] Artificial silk is now used extensively in the manufacture of trimmings, braids, embroidery flosses, hat ornaments, gloves, hosiery, sweaters and knit-fabrics, necktie fabrics, and in combination with wool, silk or cotton for various dress goods and fancy fabrics, velvets, satins, draperies, upholstery and carpet goods.

[2] It is also interesting to note the sources of these importations:

Country.	1914.	1919.	1920.	1921.
		(In Pounds.)		
Austria-Hungary	47,396	.....	5,557	22,418
Belgium	584,181	.....	508,698	479,239
France	140,220	2,455	105,476	227,459
Germany	488,978	31,391	44,119	89,708
Italy	59,808	.....	203,446	515,227
Netherlands	4,867	.....	294,362	163,467
Switzerland	157,675	121,913	664,418	563,739
United Kingdom	1,274,134	114,687	358,235	525,388
Canada	2,047	5,676	21,729	21,672
Japan	.....	22,000	42,526	4,635
Other countries	.....	.....	3,361	72
Total	2,759,306	298,122	2,251,927	2,613,024

The domestic production of artificial silk in this country is given as follows (*War Industries Board Bulletin* No. 25, 1919).

Year.	Pounds.	Year.	Pounds.
1913	1,566,000	1916	4,744,000
1914	2,445,000	1917	6,687,000
1915	4,111,000	1918	5,828,000

The domestic production of artificial silk as given by another authority is as follows:

Year.	Pounds.	Year.	Pounds.
1922	24,406,000	1917	6,687,000
1921	15,000,000	1916	4,744,000
1920	8,000,000	1915	4,111,000
1919	8,000,000	1914	2,445,000
1918	5,828,000	1913	1,566,000

The world's production of artificial silk is given as follows:

	In Pounds.
United States	23,500,000
England	15,340,000
Germany	12,584,000
Belgium	6,292,000
France	6,292,000
Holland	2,516,800
Switzerland	1,887,600
Austria	1,573,000
Hungary	1,887,600
Poland	943,800
Czecho-Slovakia	629,200
Italy	6,292,000
Total	79,738,000

The importations of artificial silk into the United States for

1913 were 2,400,000 pounds
1922 were 23,500,000 pounds

For comparison the importations of raw silk for

1913 were 26,050,000 pounds
1922 were 48,150,000 pounds

In England the output of artificial silk (1919) was about 10 tons per day, in Germany 5 tons, and in France 4 tons daily.

The Tubize factory in Belgium had a pre-war capacity of about 10,000 pounds per day. Since the war it has rapidly been reconstructed and is now operating at even a higher capacity. This plant uses the Chardonnet process, but is understood to be changing over to the viscose method. Artificial silk is now manufactured in England, Switzerland, Belgium, Poland, Germany, Russia, Italy and Japan, and the United States.

CHAPTER XXII

LINEN

1. The Flax Plant.—Linen is the fiber obtained from the flax plant, botanically known as *Linum usitatissimum*. Botanists recognise upward of one hundred species of the flax plant, but, of all these, the only one possessing industrial importance and the only one readily cultivated is the *Linum usitatissimum*, which has a blue flower. The North American Indians have long used the fiber of *L. lewisii*, which differs from the ordinary cultivated flax in having three stems growing from a perennial root. The most ancient species of flax brought under cultivation is thought to be *L. angustifolium;* the Swiss lake-dwellers are said to have grown it, as also the ancient inhabitants of northern Italy. The flax cultivated in the eastern countries, in Assyria and Egypt, appears to have been the common variety *L. usitatissimum*. Greek or spring flax, *L. crepitans*, is a small plant somewhat cultivated in Russia and Austria. Two other varieties are also cultivated to some extent in Austria, perennial flax (*L. perenne*) and purging flax (*L. catharticum*). The flax employed by the North American Indians for making fish nets was also a perennial plant, *L. lewisii*.

The fiber is prepared from the bast of the plant by a process called *retting*, which has for its purpose the separation of the fibrous cellulose from the woody tissue and other plant membranes. Historically linen appears to have been the earliest vegetable fiber employed industrially, having been used at a much earlier date than cotton. Egyptian linen fabrics (mummy-cloths) have been found which are probably over 4500 years old. Flax is mentioned in the book of Exodus as one of the products of Egypt in the time of the Pharaohs. Solomon purchased linen yarn in Egypt and Herodotus speaks of the great flax trade of Egypt. Numerous pictorial representations of the cultivation and preparation of flax are sculptured on the walls and tombs of Thebes, showing the varieties of flax in the red and white flower, the manner of pulling, retting, etc., as practiced when Jacob dwelt in the land of Goshen.[1]

[1] By some good authorities grave doubt is expressed that the so-called "linen" mentioned in the Bible was derived from the flax plant at all, it being pointed out that flax is indigenous to the temperate climates of Northern Europe but cannot be grown in the hot climates included in Bible lands. It is claimed that the mummy cloth of the ancient Egyptians was made from ramie fiber rather than from flax.

Though grown more or less in every country, at present the cultivation of flax is principally carried on in France, Ireland, Belgium, Holland, Russia, United States, and Canada.[1]

Only in the vicinity of Yale, Michigan, at Northfield and Heron Lake, Minnesota, and at Salem and Scio, Oregon, is flax cultivated in America for the production of spinning fiber. In all these localities the seed is saved, and it is doubtful if the industry would yield sufficient profits from the production of the fiber alone to warrant its continuance under present conditions.[2] New England formerly cultivated flax on the extensive scale for the fiber, but this was rapidly replaced by the introduction of cotton manufacturing, which together with the exhaustion of the soil, led to the abandonment of this industry in that part of the United States early in the nineteenth century.

The Department of Agriculture gives the following marks of the commercial grades of flax imported into the United States:

From Russia: Russian flax is known either as *Slanetz* (dew-retted) or *Motchenetz* (water-retted); ungraded fiber is called *Siretz*. The latter comes chiefly from St. Petersburg, and is known under the names of Bejedsk, Krasnoholm, Troer, Kashin, Gospodsky, Nerechta, Wologda, Jaraslav, Graesowetz, and Kosroma; all these varieties are slanetz. Pochochon, Ouglitz, Rjeff, Jaropol, and Stepurin are motchenetz. From Archangel are brought slanetz varieties known as First Crown, Second Crown, Third Crown, Fourth Crown, First Zabrack, and Second Zabrack. From Riga are obtained motchenetz varieties graded from the standard mark K through HK, PK, HPK, SPK, HSPK, ZK, GZK, and HZK.

From Holland: Dutch flax is graded by the marks $\frac{\text{I}}{\text{V}}$, $\frac{\text{II}}{\text{V}}$, VI, VII, VIII, IX.

From Belgium: Flemish flax (or blue flax) includes Bruges, Thisselt, Ghent, Lokeren, and St. Nicholas, and is graded as $\frac{\text{II}}{\text{IV}}$, $\frac{\text{I}}{\text{V}}$, $\frac{\text{II}}{\text{V}}$, VI, VII, VIII, IX. Courtrai flax is graded as $\frac{\text{I}}{\text{III}}$, $\frac{\text{II}}{\text{III}}$, $\frac{\text{I}}{\text{IV}}$, $\frac{\text{II}}{\text{IV}}$, $\frac{\text{II}}{\text{V}}$, $\frac{\text{I}}{\text{V}}$, VI.

[1] Japan is rapidly attaining prominence in flax growing. It is estimated that 83,464 acres of flax were grown in the Northern Island during 1920. This is the largest crop ever grown; unfortunately, the quality was poor owing to heavy rains. Japan now ranks fourth among the flax-producing countries, but the yield per acre is less than half that of Ireland—200 lbs. as compared with 450 lbs. This is largely due to inferior seed and careless farming. The Agricultural Department of Hokkaidô Government is dealing with the question of seed selection, and the farmers have formed local guilds and propose to set up a Central Association in Sapporo to distribute seed, advance loans, and undertake the distribution of the fiber. Each local guild is eventually to run a scutching mill of its own. There are already 65 scutching mills in Japan.

[2] *Yearbook*, Dept. Agric., 1903.

Furnes and Bergues flax is graded A, B, C, D. Walloon flax is graded II, III, IV. Zealand flax is graded IX, VIII, VII, VI. Friesland flax is graded D, E, Ex, F, Fx, Fxx, G, Gx, Gxx, Gxxx.

From France: French flax is known by the districts of Wavrin, Flines, Douai, Hazebrouck, Picardy, and Harnes.

From Ireland: Irish flax comes as scutched and mill scutched, and is known by the names of the counties in which it is raised.

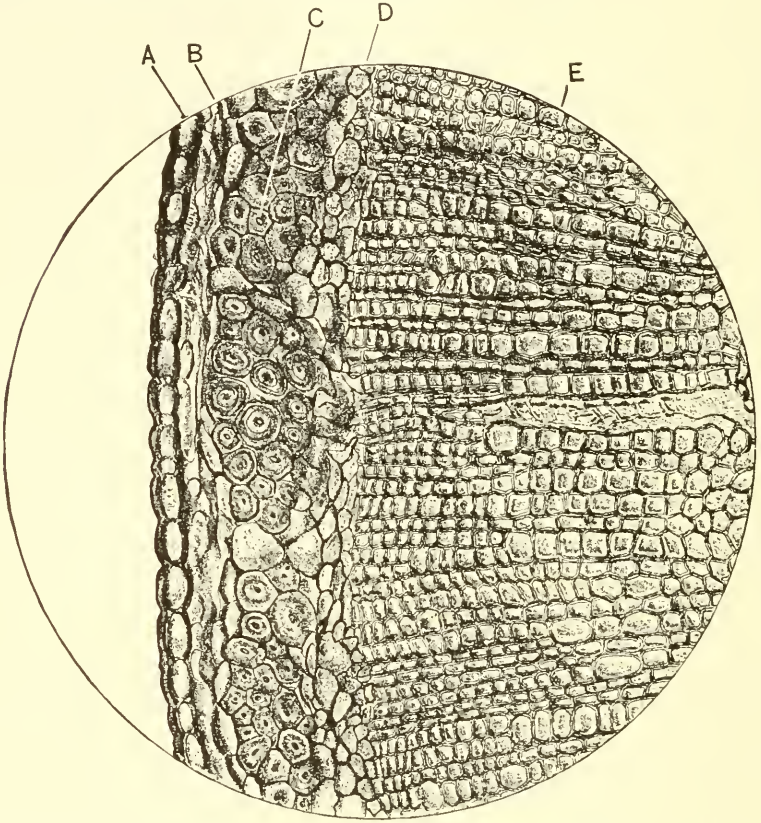


FIG. 292.—Cross-section of Flax-straw. *A*, Layer of cuticular cells; *B*, intermediate layer of cortical parenchym; *C*, bast fibers in groups, being the flax fibers proper (note secondary thickening of cell-walls); *D*, cambium layer; *E*, woody tissue. (Cross and Bevan.)

From Canada: This flax has no standard of marks or qualities.

The flax plant is annual in growth and rather delicate in structure. It grows to about 40 inches in height; the stem is slender, branching only slightly at the top, and bears naked, lanceolate, alternate leaves. The flower is mostly sky-blue, though sometimes white; the seed-capsules are five-lobed and globular, and of the size of peas. The bast tissue, which is

used for the fiber, is situated between the bark and the underlying woody tissue (Fig. 292).

Flax fiber is from 12 to 36 ins. in length, silver gray when dew-retted, yellowish white when water-retted, capable of fine subdivision, soft and flexible, and is the strongest of the fine commercial bast fibers. It is used for making linen sewing thread, shoe thread, bookbinders' thread, fishing-lines, seine twine, the better grades of wrapping twine, and knit underwear, and for weaving into handkerchiefs, towelling, table linen, collars and cuffs, short bosoms, and dress goods. The finer grades of linen damasks are imported, as the weaving of these goods is slow work, and requires a kind of labor not commonly found in this country.

Fig. 293.—The Ancient Flax Plant. (*Linum angustifolium.*) (After Bulletin U. S. Dept. Agric.)

Generally, about two bushels of flaxseed are sown per acre, and the yield in finished fiber is from 600 to 800 lbs., having a market price of about 12 cents per pound (1913). The yield of seed is from 8 to 10 bushels of 52 lbs. each. The growing of a flax crop is very exhausting to the soil; potash and phosphoric acid are the chief ingredients that the soil requires to produce a good crop of flax for either fiber or seed. It requires from 400 to 600 lbs. of mineral or phosphate fertilisers per acre, besides barn-yard and other manures, to keep the soil in condition, and then only two to three crops can be raised in succession.

The flax plant is subject to a number of diseases which at times may become epidemic and cause great injury to the crop. The Agricultural Department of Ireland recently (1920) made a detailed investigation of these diseases. They are distinguished as follows: *seedling-blight* due to a parasitic fungus; this disease spreads rapidly in wet weather but is checked by dry atmosphere and soil; it can be somewhat controlled by suitable disinfection, but a perfect method for this has not yet been discovered. *Browning* is also due to a fungus; the upper parts of the plant become brown and brittle and yield a short fiber; it may be controlled by properly disinfecting the seed. *Rust* and *firing* are due to the attacks

of a parasitic fungus belonging to the group of rusts. Firing spoils the appearance of the fiber and weakens it in spots. *Yellowing* is probably due to a potash starvation of the soil and is cured by applying proper fertilizer. Another disease known as *dead stalks* is also due to a fungus. *Dodder*, which is a parasitic twining plant that lives on the flax, is also a pest. Another enemy is the flax *flea beetle*, whose depredations are sometimes very serious.

The following table shows the production and consumption in the world's flax trade for 1913:

Country.	Production.	Imports.	Exports.	Available for Consumption.
	(In Gross Tons.)			
Russia	837,697	522	268,138	570,081
Austria-Hungary	39,159	53,586	5,162	87,583
France	21,624	111,111	84,447	48,288
Belgium	17,606	192,946	72,345	138,207
United Kingdom	12,652	99,122	5,244	106,530
Italy	2,559	2,715	1	5,273
Sweden	218	2,613	.....	2,831
Germany	.....	92,536	42,818	49,718
United States	.....	11,634	.....	11,634
Total	931,515			

The total production of flax, therefore, prior to the Great War was approximately 2,000,000,000 lbs., of which by far the greater part was produced in Russia. Since the Russia Revolution, however, the production of flax has greatly decreased in that country, and at the present time (1923) does not amount to more than about 25 percent of the pre-war figure.

Besides being cultivated for its fiber, the flax plant is also grown for its seed, which yields the valuable oil known as linseed. It possesses good drying qualities, and hence is extensively used for the preparation of paints and varnishes. The best seed-flax is grown in tropical and subtropical countries, whereas the best fiber-flax is grown in more northern climates. The seed obtained from the latter variety, though utilised as a by-product, produces only an inferior grade of oil. The oil-cake left after expressing the oil from the seed is an excellent cattle-food and is largely used for this purpose.

There are large quantities of flax grown in America, chiefly in the Northwestern States; but it is grown almost entirely for seed, the plant being allowed to ripen fully before harvesting, and the flax straw being

burned to get rid of it. The United States, in fact, furnishes about one-fourth of the world's supply of linseed oil. In 1900–1901 the yield of oil was about 40,000,000 gallons. The Argentine Republic is the greatest flax-growing country in the world; but the plant, in this case, too, is grown only for the seed and the straw is burned. The yield of oil from this country is about 55,000,000 gallons, or about one-third of the world's supply. Russia has a large acreage devoted to the cultivation of flax-seed; the fiber, however, is of minor importance, being woody and subject to great waste in preparation. In India flax is also mainly grown for the seed.

2. The Retting of Flax.—The flax plant, after attaining its proper growth, is either cut down or pulled up by its roots, and subjected to a process technically known as *rippling*, the plants being drawn through a machine consisting of upright forks which remove the seeds and leaves. The remaining stalks are then tied in bundles and placed in stagnant water, where they are allowed to remain for a number of days. Active fermentation soon starts, resulting in the decomposition of the woody tissues enclosing the cellulose fibers. When the process has gone sufficiently far, the bundles of fermented stalks are removed and passed through a number of mechanical operations, whereby the decomposed tissues are removed and the linen fibers are isolated in a purified condition. This method of retting with stagnant water is known as "pool-retting." As the fermentation causes the evolution of considerable gas, in order to keep the bundles of stalks submerged, they are loaded with stones or boards. The time of steeping in the water varies with circumstances from five to ten days. Another method of retting is to steep in running water. The famous Courtrai flax of Belgium is retted in this manner in the river Lys. The flax-straw, after pulling, is placed in crates and submerged in the water of this stream for a period of four to fifteen days, depending on the temperature and other conditions. Courtrai flax is of a creamy color, whereas pool-retting flax has a rather dark bluish brown color. The excellent qualities of the Courtrai flax are said to be due to the action of the soft, slowly running, almost sluggish waters of the river Lys, and to the peculiar ferment existing therein. Another method employed for obtaining the fiber from flax is known as dew-retting, as the flax-straw is spread out in a field and exposed for a couple of weeks to the action of the dew and the sun. Dew-retting, however, gives the most uneven and least valuable product of the three methods employed, and the fiber is rather dark in color. There have also been several chemical methods proposed for retting flax, such as heating with water under pressure, boiling with solutions of oxalic acid, soda ash, caustic soda, etc. None of these however, have proved of any industrial value, and the older natural methods are still adhered to. Additions of various chemicals to the retting waters

have at times proved of value, hydrochloric or sulfuric acid sometimes being used to advantage.

Dodge gives the following notes relative to the retting of flax: "For dew-retting a moist meadow is the proper place, the fiber being spread over the ground in straight rows at the rate of a ton to an acre. If laid about the 1st of October and the weather is good, a couple of weeks will suffice for the proper separation of the fiber and woody matter. For pool-retting the softest water gives the best results, and where a natural pool is not available, such as the 'bog-holes' in Ireland, 'steep pools' will have to be built. A pool 30 ft. long, 10 ft. wide, and 4 ft. deep will suffice for an acre of flax. Spring water should be avoided, or, if used, the pool should be filled some weeks before the flax is ready for it, in order

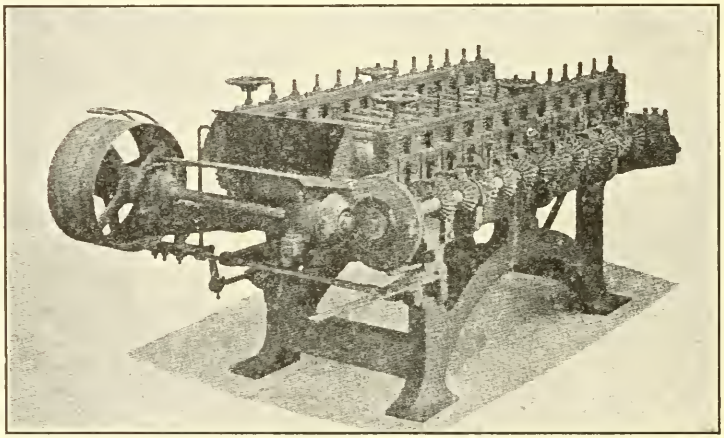


Fig. 294.—Flax Breaker.

to soften the water. It should be kept free from all mineral and vegetable impurities. The sheaves are packed loosely in the pool. Fermentation is shown by the turbidity of the water and by bubbles of gas. If possible, the thick scum which forms on the surface should be removed by allowing a slight stream of water to flow over the pool. The fiber sinks when decomposition has been carried to the proper point, though this is not always a sure indication that it is just right to take out. In Holland the plan is to take a number of stalks of average fineness, which are broken in two places a few inches apart. If the woody portion or core pulls out easily, leaving the fiber intact, it is ready to come out. The operation usually requires from five to ten days."

Schenck's method of retting is to steep in warm water, a constant temperature of 35° C. being maintained. It is said that the fermentation may be completed by this method in fifty to sixty hours, and gives a larger

yield and a better product than the natural processes of retting. In steam-retting, the bundles of flax straw are placed in iron cylinders and heated with live steam or hot water under pressure, but the process does not appear to be successful. Loppens and de Swarte [1] introduced a method in which the flax straw is placed upright in a tank through which passes an upward current of water. The dissolved matters form a heavy solution which falls to the bottom.[2]

The intercellular substance holding the flax fibers together consists mostly of calcium pectate, and the real object of retting is to render this substance soluble, so that it may be removed by the after-processes of treatment. Winogradsky has succeeded in isolating the particular organism that is the active agent in the pectin fermentation.[3] It is an anaerobic bacillus which readily ferments pectin matters, but has no action on cellulose.

Beijerinck and van Delden ascribe the bacterial action in flax retting to a fermentation of the pectose first into pectin, and then into sugars, through the action of an enzyme, *pectinase*, secreted by the bacteria. According to Behrens the active agents in dew-retting are mould fungi.

The water-retting of flax is described by Störmer as a biological process induced by the action of definite organisms, the chief of which is an anaerobic *Plectridium*, which in the absence of air ferments the pectin substances of the cellular material uniting the parenchymous tissues, and thus causes a loosening of the bast fibers.[4] The exclusion of oxygen, which is necessary that the fermentation may be set up, is brought about by numerous oxygen-consuming bacteria and fungi. The products formed by the fermentation of the pectin substances are hydrogen and carbon dioxide and organic acids, especially acetic and butyric and small quantities of valeric and lactic acids. The injurious action of the acids produced, especially butyric acid, may be considerably diminished by adding alkali or lime to the retting liquid. It is also advantageous to

[1] *Brit. Pat.* 14,781 of 1895.

[2] According to Crochet (*Ger. Pat.* 146,956) the flax is boiled in a bath containing lime water, caustic soda and crystal soda (the latter seems to be incompatible as it would precipitate the lime), then treated with a hot soap bath. Bonney and Pritchard (*Ger. Pat.* 199,042) use sodium borate and soap solution, while Summers (*Ger. Pat.* 197,659) uses only a solution of potash. Probably the best chemical retting is done by the old Bauer process (*Ger. Pats.* 68,807 and 80,023) in which the flax is treated for one hour at 212° F. with a ½ percent solution of sulfuric acid, and afterward with a hot dilute solution of caustic soda (see *Chem. Zeit.*, 1906, p. 983).

[3] There seems to be some confusion as to the exact species of this organism. Winogradsky designates it as the *Bacillus amylobacter*, while Beijerinck and van Delden call it *Granulobacter pectinovorum*.

[4] Prof. Rossi-Portici (see *Oesterr. Wollen. Ind.*, 1908, pp. 641 and 1409) has prepared in a successful commercial manner the particular ferment for flax retting; it is called *Bacillus comesii* and is said to produce complete retting in about three days.

inoculate the liquid at the beginning of the retting with pure cultures of the anaërobic *Plectridium*.

By adding salts promoting the growth of the bacillus to the water employed in retting, it has been found possible to reduce the time of retting very considerably.

An interesting method of retting flax is described by Jean, Doumer and Romain [1] as follows: The retting takes place in a hermetically closed vessel with the addition of water heated to 40° to 50° C. and the application of an air pump. The flax is placed in a vessel between two wire gauze bottoms. By means of the pump all of the air is exhausted and the flax is treated in the water for several days. The retting is said to be complete in five to six days. It would seem, however, that this method requires a large amount of apparatus for a small production of fiber.

Krais [2] recommends the use of a 1 percent solution of sodium bicarbonate for retting. The addition of 0.5 to 1 percent of sodium sulfite to the retting liquor is also recommended as it gives a lighter color product. The disagreeable odor of the retting liquor may be improved by adding some dextrose along with the sodium bicarbonate.

3. Preparation of Flax in Belgium.—According to Carter the method of preparing flax fiber in Belgium is as follows: The flax straw, before it becomes quite ripe, is pulled up by the roots in handfuls and spread on the ground in rows, the handfuls laid with tops and roots alternating, which prevents the seed bolls from becoming entangled when the handfuls are again lifted. The laborious operation of the hand-pulling of flax is likely to be pretty generally superseded in the near future by machine pulling. The straw is stacked as soon after pulling as possible, the handfuls resting against each other; the root ends will spread out, and the tops join, like the letter A. In six or eight days the straw is dry enough to be tied into sheaves like corn sheaves. It is then ricked and allowed to stand in the field until the seed is dry enough for stacking. Under the Courtrai system the seed is taken off during the winter and the straw restacked or kept under cover until the spring, when it is sometimes retted. It is generally considered better, however, that the flax straw be kept for at least a year, and it is sometimes kept for two years before steeping. The seeders bind the straw into parallel bundles about 12 ins. in diameter, which for steeping are packed either horizontally or vertically in large wooden crates or *ballons*, lined with straw. The upright position is usually adopted, as it is said to be more favorable to the production of light-colored fiber, as no sediment or deposit can rest upon it at any stage of fermentation. Straw and boards are afterwards placed on top, and the crate thus charged slid into the river and anchored in the stream,

[1] *Leipziger Monatschrift Textilindustrie*, 1892

[2] *Zeit. angew. Chem.*, 1920, p. 102.

and weighted with stones so that it is submerged a few inches below the surface. In a few days fermentation begins, and as it proceeds additional stones must be added from time to time in order to prevent the rising of the crates through the evolution of gas. As a rule, after steeping for a few days, the flax is removed from the crates and set up in hollow sheaves to dry, the advantage of the interruption of the retting process at this stage being that exposure to the sun and air kills the microbes of putrefaction which have developed, so that the strength of the fiber remains unimpaired. When dry, or later, it is repacked in the crates and again steeped until retting is complete—seven to twelve days, according to the temperature, quality of flax, etc. The duration of steeping is, say, about seven days in August, ten in May, and twelve in October, when the temperature of the water is much lower. Fine thin stems require a longer time to ret than do stouter stems. The end of the process is accurately determined by occasionally examining the appearance of the stems and applying certain tests. The bundles of straw should feel soft, and the stems be covered with a greenish slime, easily removed by passing them between the finger and thumb. When bent over the forefinger, the central woody portion should spring up readily from its fibrous envelope. If a portion of the fiber is separated from the stem and suddenly stretched, it should draw asunder with a dull and not a sharp sound.

When retting is complete, the flax straw is carefully removed from the crates and again set up in sheaves to dry, this time in the shape of a hollow cone. The retted and dried straw is then stored in barns and sheds until winter, when scutching, or cleaning the fiber from the woody part of the stem, takes place. The scutch mill machinery consists first of all of a breaker or crushing rollers, a series of pairs of fluted rollers which crush the straw and break up the " boon " into small pieces, which in the case of Courtrai and other flax which has been skillfully retted, are easily separated from the fiber by the strokes of a beater. The best flax rollers are in sets of 5, 6, or 8 pairs, the rollers being about 8 ins. in diameter and having from 16 to 24 flutes, $\frac{1}{2}$ in. to 1 in. deep.

The broken-up woody matter is then knocked out of the fiber, as the scutchers hold it in handfuls in a notch in an upright plank or stock, by revolving beaters or handles of wood, which, fixed upon a cast-iron rim keyed upon a shaft making about 175 revolutions per minute, make about 2100 strokes per minute, there being 12 blades to the round in a Belgian scutch mill. The effective diameter of the circle being 4 ft. 6 ins., their speed is nearly 2500 ft. per minute.

An acre of fairly good flax is estimated to weigh " on foot," or when freshly pulled, about 5 tons. In drying it loses about 55 percent of its weight. Rippling or seeding reduces its weight by another 25 percent,

steeping by another 25 percent; and if the yield of fiber in scutching be taken at 20 percent, the yield of fiber is only about 5½ percent of the weight of the green straw.

Of the various systems of retting, that effected in the slow current of running water undoubtedly gives the best results as regards color and quality of the fiber produced. Of recent years Continental experts have studied the question of producing the same effects by other means, and a most practical system introduced by Messrs. Legrand and Vansteinkiste has been adopted by a number of flax factors, both on the Lys and far from it, and a number of retteries built.

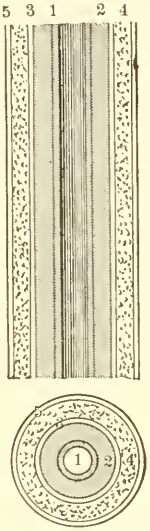


Fig. 295.—Diagram of Flax-straw. (1) Marrow; (2) woody fiber; (3) cambium layer; (4) bast fiber; (5) rind or bark. (After Witt.)

4. Impurities in Raw Flax.—The substances classified in a general way as "pectin matters" form the intercellular matter between the elemental cells of the bast fibers, and serve the purpose of a cementing medium to hold the small elements of the fiber together. Their character is that of a resinous gum. By certain investigators this resinous matter has been given the name *pectose*. It is hardly likely, however, that this substance consists of a single chemical compound, but it is more probably a mixture of several chemical individuals. By heating with dilute acid, pectose is converted into a series of products which have received considerable attention from botanical chemists; the products include *pectin*, *para-pectin*, *meta-pectin*, *pectosic acid*, *pectic acid*, *parapectic acid*, *meta-pectic acid*, etc. Pectin and especially para- and metapectin are soluble in water, whereas pectic acid is not. Therefore, if it is desirable to separate the elements of a vegetable tissue, it is necessary to stop the action of the retting agents before the formation of pectic acid. In the case of the preparation of linen, however, it appears to be necessary not to dissolve out all the pectose derivatives from the fiber, but to allow of the formation of some pectic acid, as this makes the surface of the fiber more brilliant and leaves it stronger and more elastic.

It has been claimed that fatty acids exert a solvent action on the resinous and pectin matters present in vegetable fibers, and a method for the decortication of flax and other bast fibers has been devised as follows: The raw fibers are impregnated with boiling soap solutions, after which ammonium chloride is added, which liberates the fatty acids. After several hours' treatment these dissolve all gummy and resinous matters; the fibers are then treated with weak caustic alkali, after which they are

washed and dried when they should be thoroughly disintegrated. Good results are said to be obtained by this method.

The flax stalks, after being deprived of their leaves and seeds by rippling, are known as flax-straw. The latter in the air-dry condition contains from 73 to 80 percent of wood, marrow, and bark, and 20 to 27 percent of bast. The general structure of flax-straw, and of bast stalks in general, is shown in the schematic drawing (Fig. 295).

According to Prof. Hodge (of Belfast), the proportions among the constituent parts of the flax plant are as follows:

	Pounds.
Dried flax plants	7770
Bolls	1946
Seed	910
Raw fiber stalks	5824
Loss in steeping	1456
Retted stalks	4368
Finished fiber	702

Hence, the weight of the fiber was equal to about 9 percent of the dried flax stalk with the seed-bolls, or to 12 percent of the bolted straw, or to over 16 percent of the retted straw.

According to Schenck (American process), the following proportions were obtained.

	Tons.
Dried flax straw	100
Bolls	33
Loss in steeping	27.5
Separated in scutching	32.13
Finished fiber	5.9
Low and pluckings	1.47

In the carding and spinning of flax there is a considerable amount of waste produced consisting of short fibers varying in length from $\frac{1}{2}$ to 3 ins. Considerable endeavor has been expended in efforts to utilise this waste flax for the spinning of low grades, but not with very good success. The chief difficulty in the spinning of waste flax is due to the fact that the fibers are stiff and lack coherence, which causes them to separate in the spun yarn and thus leave the latter without any strength. A recent German process for the utilisation of waste flax for spinning attempts to give the short fibers a greater softness and flexibility together with sufficient curl to make the fibers more coherent when spun into a yarn. The flax waste is first beaten or heckled in order to remove shives, and is then boiled for one hour in a 5 percent solution of caustic soda. This treatment is said to cause a curling of the fibers. The material is then washed and placed in a second bath consisting of 500 parts sal soda, 250 parts soft soap, 1000 parts cream tartar, 150 parts painter's glue, 250

parts olive oil, 100 parts acetic acid, dissolved in 220 parts of water, and heated to about 115° F. This solution forms a milky acid emulsion

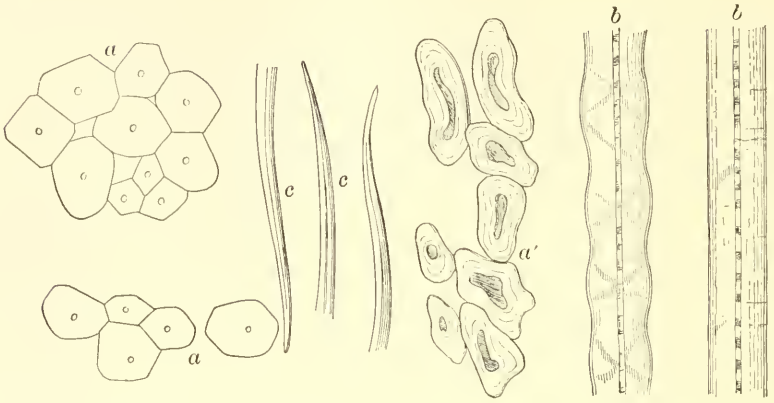


Fig. 296.—Flax Fibers. (×400.) *a*, *a'*, Cross-sections; *b*, longitudinal views; *c*, ends. (Cross and Bevan.)

in which the fiber is left for one hour. It is then hydroextracted and placed in a bath containing lactic acid. It is claimed that by carding the material thus treated a woolly soft fleece is obtained, which may readily be spun into yarn.

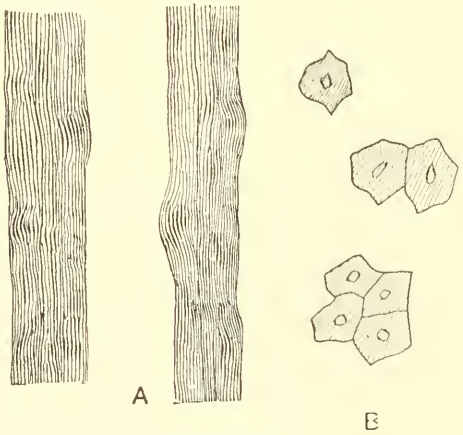


Fig. 297.—Flax Fiber. (×300.) *A*, Longitudinal view, showing jointed structure and tracing of lumen; *B*, cross-sections.

5. Microscopy of Linen Fiber.—The linen fiber as it is obtained from the plant and as it appears in trade is in the form of filaments, the length of which varies considerably with the manner and care employed in decorticating, and may be from a few inches to several feet. These filaments are composed structurally of small elements or cells, consisting of practically pure cellulose. They are uniformly thick, and average 12 to 25 microns in diameter and 25 to 30 mm. in length. Their structure is rather regular, being cylindrical in shape, though somewhat polygonal in cross-section. A peculiarity in the appearance of the cells is the occur-

rence of faintly marked "dislocations" or so-called "nodes" extending transversely and often in the form of an "X."[1] These nodes may be made more apparent by staining with Methyl Violet or chlor-iodide of zinc solution. The cell-wall is quite uniform in thickness, and the lumen or internal canal is very narrow, and often is but faintly apparent as a dark line. The cross-section of the linen fiber shows no yellow circumferential stain when treated with sulfuric acid, though the lumen shows up as a yellow spot. Wiesner gives the following dimensions of several varieties of flax filaments:

Kind of Flax.	Mean Length of the Purified Flax Fiber, Mm.	Mean Breadth, Mm.
Egyptian	960	0.255
Westphalian	750	0.114
Belgian Courtrai	370	0.105
Austrian	410	0.202
Prussian	280	0.119

Good flax should average 20 ins. in length and be free from fibers less than 12 ins. in length.

Dodge gives the following dimensions for the elements of the flax fiber: Length, 0.157 to 2.598 ins.; mean, about 1 in.; diameter, 0.006 to 0.00148 in.; mean, 0.001 in.

Hanausek[2] gives a microscopical method of distinguishing between linen and tow yarns, as follows:

1. Linen yarn consists of fiber cells which mostly have narrow lumens and pointed ends, and is mostly free from other tissues of the stem.

2. Tow yarn consists of fiber cells with both narrow and broad lumens, and always contains epidermal cells.

Herzog also points out that fibers which he designates as "unripe" occur in tow. These fibers are from the upper part of the flax stems and have broad lumens with abundant remains of protoplasmic contents.

The bast-cells of the flax fiber may be isolated by treatment with a dilute chromic acid solution. They are cylindrical in form and taper to a point

[1] Höhnel (*Ueber den Einfluss des Kindendruckes auf der Beschaffenteil der Bastfasern, Jahrbuch, Wiss. Bot.*, vol. 15, p. 311) considers that these dislocations or cross-folds are of physiological origin resulting from inequalities in the radial pressure of the tissues in the plant. Schwendener (*Ueber die "Verschiebungen" der Bastfasern. Ber. Deutsch. Bot. Gesell.*, vol. 12, p. 239), on the other hand, considers them as resulting from artificial influences during the processes of preparation, as fibers obtained by simple retting in water show almost a complete absence of such distortions

[2] *Microscopy of Technical Products*, p. 77.

at each end. At the middle they measure 12 to 26 microns, with an average of about 15 microns.[1] The length varies from 4 to 66 mm., with an average of about 25 mm. The ratio of the length of the cell

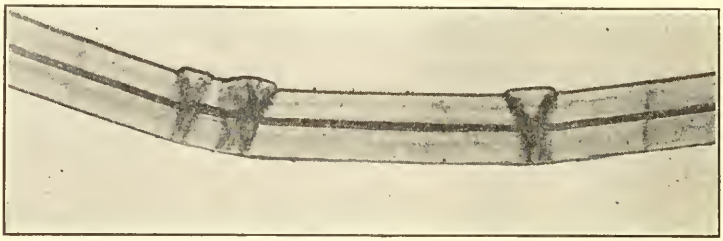


Fig. 298.—Flax Fiber Showing Nodes Stained with Chlor-iodide of Zinc. (Herzog.)

to its breadth is about 1200. Under the microscope the surface of the cell appears smooth or marked longitudinally, with frequent transverse fissure lines and jointed structures. On treatment with chlor-iodide of zinc

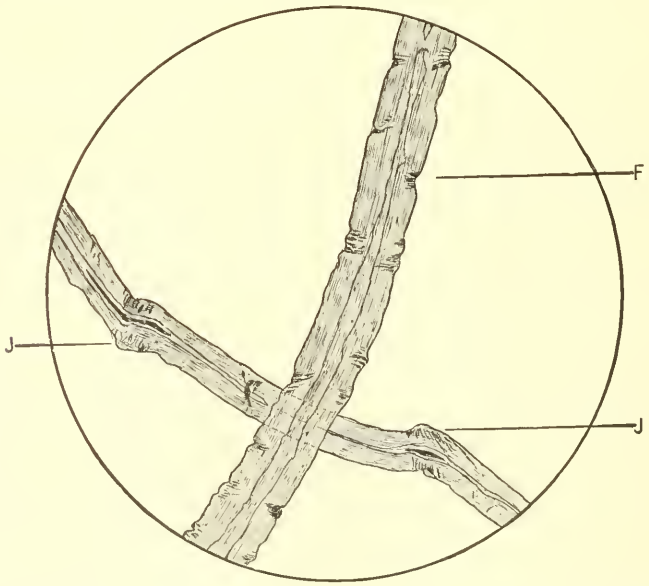


Fig. 299.—Flax Fiber. (×300.) Stained with Methyl Violet. *J*, Joint-like formations; *F*, fissure-like markings. (Micrograph by author.)

the latter are colored much darker than the rest of the cell and are thus rendered more apparent. The lumen appears in the center of the cell as a narrow yellow line, and it is usually completely filled with protoplasm. With iodine and sulfuric acid linen gives a blue color, which, however,

[1] According to Vétillard, 15 to 37 microns, with an average of 22 microns.

develops less quickly than with cotton; with tincture of madder an orange color is produced, while fuchsine (followed with ammonia) gives a permanent rose color in contradistinction to cotton. These tests, however, are only applicable to unbleached linen, for the cellulose of bleached linen shows little or no chemical difference from that of cotton. In cross-section the cells of flax are polygonal, with rounded edges, show a small lumen, and a relatively thick cell-wall. In these respects they are very similar to hemp, but may be distinguished from the latter, however, in that they do not aggregate in thick bundles, but are more or less isolated from each other, so that the cross-section frequently shows but one cell, and seldom more than three or four.

Other differences from hemp exhibited by the linen fiber are: (*a*) the cross-section does not show an external yellow layer of lignin when treated with iodine and sulfuric acid; (*b*) it gives reactions for pure cellulose only, that is, iodine and sulfuric acid color the fiber a pure blue, and aniline sulfate gives no color, though at times there are shreds of parenchymous tissue present which are colored yellow by this latter reagent and appear to be lignified; (*c*) the lumen of the hemp fiber is seldom filled with yellowish protoplasm like that of the linen fiber; (*d*) the linen fibers end in sharp points, whereas those of hemp do not.

6. Chemical and Physical Properties.—The flax fiber appears to consist of pure cellulose and shows no signs at all of being lignified. Though the flax fiber is generally considered as non-lignified, Höhnel [1] is of the opinion that very short sections with lignified cross-walls occur between long sections with walls of pure cellulose. Herzog determined the lignin in fibers from different parts of the plant by the methyl oxide method, and found that fibers from the root contained 3.8 percent, from the middle of the stem 2.36 percent and from the tip of the stem 1.64 percent of lignin. By bleaching the lignin is entirely removed.

In order to isolate pure flax cellulose, Cross and Bevan have recommended the following procedure: The non-cellulosic constituents of flax are pectic compounds which are soluble in boiling alkaline solutions. The proportion of such constituents varies from 14 to 33 percent in different varieties of flax. They may be completely extracted by first boiling the fiber in a dilute solution of caustic soda (1 to 2 percent); the residue will consist of flax cellulose, with small remnants of woody and cuticular tissue, together with some of the oils and waxes associated with the latter. By treatment with a weak solution of chloride of lime, the woody tissue is decomposed, and is then removed by again boiling in dilute alkali. The remaining cellulose is then further purified from residual fatty and waxy matters by boiling with alcohol and finally with ether-alcohol mixture.

[1] *Zur Mikroskopie der Hanf und Flachsfaser, Zeitschr. Nahr. Unters. Hyg. Warenk.*, 1892, p. 30.

Flax cellulose prepared in this manner appears to be chemically indistinguishable from cotton cellulose.

Linen becomes strongly swollen by treatment with Schweitzer's reagent (see Figs. 301 and 302), but, unlike cotton, it does not completely dissolve therein. In swelling the fiber blisters considerably, but not in as regular a manner as cotton. The inner layers of the cell withstand the action of the reagent the longest and remain floating in the liquid, like the cuticle of cotton. Parenchymous and intercellular matter adhering to the fiber also remains undissolved in the reagent.

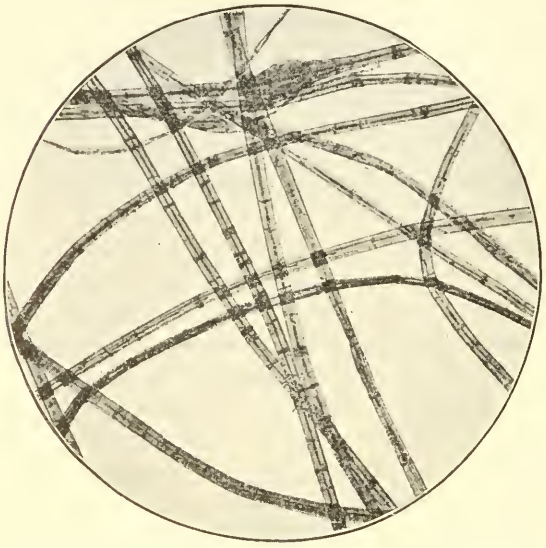


Fig. 300.—Flax Fibers Treated with Chlor-iodide of Zinc. (Herzog.)

According to Hanausek [1] by cautiously treating flax fibers with iodine and weak sulfuric acid three layers may be distinguished: first, an outer dark-blue layer becoming liquid in the reagent; second, a longitudinally striated light-blue tube; and third, a narrow yellow tube with yellow contents. If strong sulfuric acid is used the whole cell-wall changes to a blue swollen mass, and only the inner tube containing protoplasmic remains persists for any considerable time. In cuprammonia the cellulose wall goes into solution with the formation of a blue color and bladder-like swellings, while the inner tube remains as a sinuous, and in parts, almost curled thread.

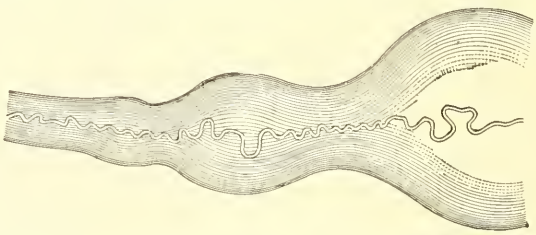


Fig. 301.—Cell of Flax Fiber Treated with Schweitzer's Reagent. (×400.) Showing insoluble cuticle of inner canal. (Wiesner.)

The **color** of the best varieties of flax is a pale yellowish white. Flax retted by means of stagnant water, or by dew, is a steel gray, and Egyptian

[1] *Microscopy of Technical Products*, p. 74.

flax is a pearl gray. The pale yellow color of flax is due to a natural pigment, but the other color arises from the decomposition of the intercellular matter, which is left as a stain on the fiber. Flax that has been imperfectly retted shows a greenish color. The natural color of linen is readily bleached by solutions of chloride of lime in a manner similar to the bleaching of cotton. But the linen fiber suffers considerable deterioration thereby. There are four grades of linen-bleaching—quarter, half, three-quarters, and full bleach. The whiter the fiber is bleached the weaker it becomes. In determining the size (or number) of bleached linen yarns, the loss in bleaching is fixed at 20 percent for full, 18 percent for three-quarters, and 15 percent for one-half bleach.

The **luster** of linen is quite pronounced and almost silky in appearance; flax that is overretted is dull in appearance. Egyptian flax is also dull, due to the cells being coated with residual intercellular matter.

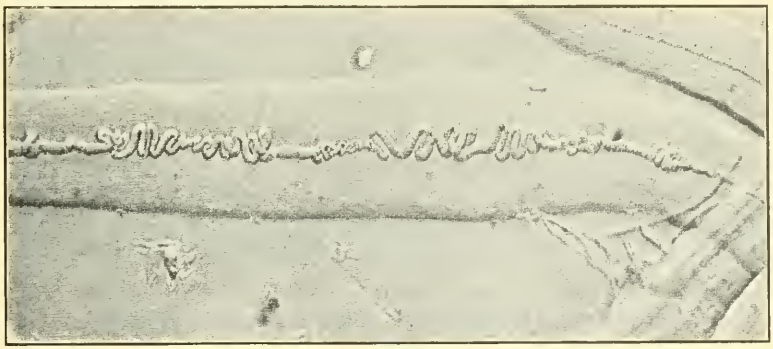


Fig. 302.—Flax Fiber Swollen with Schweitzer's Reagent. (Herzog.)

The flax fiber is much stronger than that of cotton, though overretted flax is brittle and weak. According to Spon, samples of flax fiber exposed for two hours to steam at 2 atmospheres, boiled in water for three hours, and again steamed for four hours, lost only 3.5 percent in weight, while Manila hemp under these conditions lost 6.07, hemp 6.18 to 8.44, and jute 21.39 percent.

As flax is a better conductor of heat than cotton, linen fabrics always feel colder to the touch than those made from cotton.

Cottonised flax was a name given to a product made by disintegrating flax by chemical means into a fine cotton-like material, by a process proposed by Claussen in 1851. The flax was first treated with a dilute solution of caustic soda, then impregnated with a solution of soda ash, and immersed in a dilute solution of sulfuric acid, the fibers being disintegrated by the liberation of the carbon dioxide gas. Fabrics woven from yarns of this material, however, were found to be deficient in strength,

and the process never met with commercial success. It has been suggested, however, to employ it for the preparation of absorbent lint for surgical purposes, it being claimed that the lint prepared from this material is more absorbent and antiseptic than that from cotton waste.[1]

According to Rasser[2] cottonising may be applied to any fiber having a woolly feel, such as jute, hemp, flax, typha, and the like, but chiefly to flax and hemp tows and spinning wastes, as well as to fibers derived from the pulling of rags, twine, and cloth wastes, recovered hemp and flax fibers, jute wastes, and lastly, flax and hemp grown for seed. A distinction must be made between technical and purely chemical cottonising. In technical cottonising the wastes or fibers are passed through specially constructed willows and then submitted to a crimping process. A real solution into the ultimate fibers does not occur, and only coarse yarns

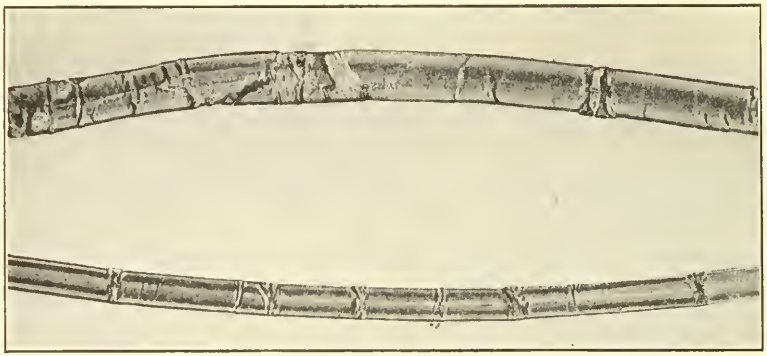


Fig. 303.—Linen Fibers under Polarised Light. (Herzog.)

may be spun from this material, which owing to single projecting hairs are not so smooth as the chemically treated fibers. In the latter case the fibers are isolated into their ultimate filaments and therefore cohere more effectively to one another when spun either by themselves, or as more

[1] By the cottonising process, short fibers are obtained either by mechanical or chemical means. By bacterial or chemical means, especially with intensive action, high yields of tow are obtained, which can no longer be used as the raw material for spinning. Fifty years ago Claussen introduced the use of flax wool, which was spun with cotton or wool, but this outlet for short fibers was not a success owing to the difficulty of spinning in machines built for the longer cotton fiber. During the war, one firm used flax, hemp and jute residues as well as nettle fibers for coarse cloths and also for more valuable fabrics. Jute residues were used in France before the war for making artificial worsted. The question has arisen again owing to the high cost of cotton So far, no great advance has been made owing to the necessity for special machinery, new methods of working and practical experience. It is suggested that German hemp, normally of less value, short flax, and tangled flax straw might be utilised. The problem is also of interest to India, Canada and the Argentine.

[2] *Monatschrift Textilindustrie.*

usual, with other better grade fibers. In the chemical process of cottonising, caustic soda and chlorine are employed, also Turkey-red oils and soaps, and oxidising substances. Hemp is more easily cottonised than flax. In order to make the cottonised fiber more suitable for spinning it is recommended to treat the fiber with strong cold caustic soda solution and then wash with water.

7. Chemical Composition of Linen.—The following analyses show the composition of two typical specimens of flax (H. Müller):

	I. Percent.	II. Percent.
Water (hygroscopic)	8.65	10.70
Aqueous extract	3.65	6.02
Fat and wax	2.39	2.37
Cellulose	82.57	71.50
Ash (mineral matter)	0.70	1.32
Intercellular matter	2.74	9.41

According to Wiesner, the ash of the linen fiber amounts to from 1.18 to 5.93 percent, and shows no evidence of crystals.

The flax fiber contains a certain wax-like substance, varying in amount from 0.5 to 2 percent. It may be extracted from the fiber by means of benzene or ether. The color of the wax varies with that of the flax from which it is obtained. It has a rather unpleasant odor, resembling flax itself. Its melting-point is 61.5° C., and its specific gravity at 60° F. is 0.9083. According to Hoffmeister, this wax consists of 81.32 percent of unsaponifiable waxy matter and 18.68 percent of saponifiable oil. Of the latter, 54.49 percent is free fatty acid. The waxy matter has a melting-point of 68° C., and apparently is a mixture of several bodies. The principal one resembles ceresin, and there are also present ceryl alcohol and phylosterin. The saponifiable matter appears to contain small quantities of soluble fatty acids, like caproic, stearic, palmitic, oleic, linolic, linolenic, and isolinolenic.

Highly purified flax appears to approximate very closely to both the composition and chemical properties of cotton. The ordinary flax fiber of trade may be said to contain about 5 percent less of cellulose than cotton, there being about that much more impurity present in the form of intercellular matter and pectin bodies. Linen, however, appears to be free from woody or lignified tissue, as it gives none of the reactions for these. Höhnel has shown, however, there are short spaces on the fiber which are strongly lignified. Most of this lignin is removed by bleaching.

The linen fiber swells up greatly when treated with an ammoniacal

solution of copper oxide, but, unlike cotton, it does not exhibit the peculiar sausage-shaped appearance, nor does it dissolve completely. The hydroscopic moisture in linen is about the same as in cotton; in fact, all vegetable fibers appear to contain approximately the same amount (from 6 to 8 percent).

The amount of "regain" allowed in the conditioning of linen at Roubaix is from 10 to 12 percent. Wiesner gives the amount of hygroscopic moisture in linen as 5.7 to 7.22 percent. The Turin Congress fixed the regain for linen at 12 percent.

Due to differences in structure, linen is more easily disintegrated than cotton, and consequently does not withstand the action of boiling alkaline solutions, solutions of bleaching powder or other oxidising agents, etc., as well as cotton.

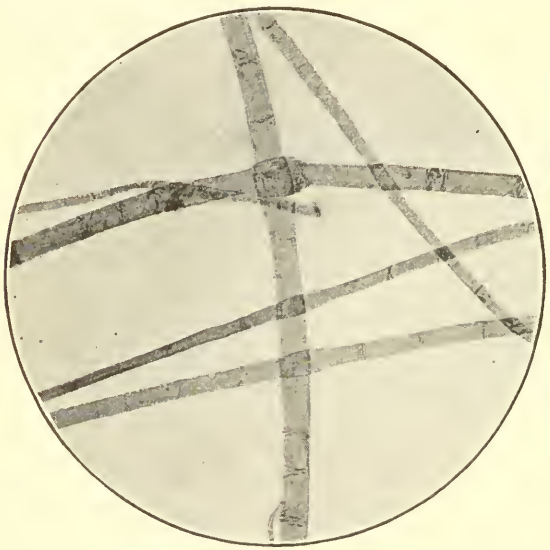


Fig. 304.—Flax Fiber. (Herzog.)

Toward mordants and dyestuffs, etc., linen does not react as readily as cotton, hence its manipulation in dyeing is more difficult. In general, however, it may be said that the dyeing and treatment of linen are practically the same as with cotton.

The oil-wax group of constituents in the flax fiber plays an important part in the spinning of this fiber, and the failure of many of the artificial processes of retting flax may be attributed to the fact that the fiber is left with a deficiency of these constituents. In the breaking down of the cuticular celluloses, whether in the retting or in the bleaching processes, these waxes and oils are separated. Their complete elimination from the cloth necessitates a very elaborate treatment, such as is represented by the "Belfast Linen Bleach."

Hoffmeister[1] has shown that the odor and suppleness of flax are due to a characteristic wax on the surface of the fiber, and if this wax is removed by suitable solvents, the fiber becomes rough, lusterless, and brittle. This wax is insoluble in water, has a specific gravity of 0.9083

[1] *Berichte*, 1903, p. 1047.

(at 15° C.) and melts at 61.5° C. It consists chiefly of a paraffin resembling ceresin mixed with glycerides of several fatty acids. It also contains phytosterol and ceryl alcohol, and a small proportion of a volatile aldehydic substance. The so-called "flax-dust" in linen factories was found to contain 10 percent of the wax.

8. Linen Yarns and their Properties.—Linen yarns are known as hand-spun or machine-spun; the former are softer and smoother and more elastic, but uneven and less rounded in form, while machine-spun yarns are stiff and rough, but of uniform thickness and perfectly round. According to the method of spinning, linen yarns are also known as dry-spun or wet-spun; the former have greater firmness, but higher numbers can be obtained by wet-spinning. Tow yarns are prepared from waste, and are characterised by numerous knots due to particles of shives. In the English system, the counts of linen yarns are expressed by the number of leas in a pound, each lea measuring 300 yds. To obtain the count of cotton yarn corresponding to the count of linen yarn, the latter number is divided by 2.8. In the French system, the count of linen yarns is the number of hanks of 1000 meters contained in 500 grams. In the Austrian system, the count indicates the number of hanks to 10 English pounds, each hank containing 3600 ells (1 ell = 30.68 ins.).

Brun [1] has given some interesting tests showing the effect of the amount of moisture on the strength of linen sail cloth. It would seem that as the amount of moisture increases the strength also increases in quite a remarkable degree. The results are given as follows:

Moisture, Percent.	Strength in Kilos.	Moisture, Percent.	Strength in Kilos
0.0	180	12.0	350
2.2	190	15.0	402
5.5	232	19.1	417
9.0	288	35.0	425

In this case the normal amount of moisture in the cloth as delivered was 9.0 percent. These figures bear out the well-known fact that fabrics of linen (and cotton as well) are much harder to tear when wet than when dry.

Higgins [2] gives the following results concerning the effect of various processes on the properties of raw linen yarn:

[1] *Chem. Zeit.*, 1893.
[2] *Jour. Soc. Chem. Ind.*, 1911, p. 1295.

Loss in Weight During Bleaching

	Weight, Grams.	Loss, Percent.	Ash, Percent.
Brown linen	92.1	....	1.28
After steeping	88.7	3.8	
After lime boiling	77.15	16.2	0.18
After lye boiling	70.93	22.9	0.08
After chemicking	69.53	24.5	0.08
Fully bleached	67.52	26.7	0.07
Half-bleached linen	.....	....	0.37

Loss in Tensile Strength

	Warp, Grams.	Filling, Grams.
Brown linen	1050	800
After lime and lye boils	890	860
After chemic	860	810
Fully bleached	780	740

9. Absorbent Flax.—Absorbent flax is often used as a substitute for absorbent cotton. As is well known, cotton is rendered absorbent by removing the gum by boiling in a closed kier. Treated in this way, cotton is used for bandaging wounds. The objection raised to absorbent cotton is that it retains the heat, thus promoting fermentation and delaying the healing of the wound. Absorbent flax is a better conductor of heat and thus is not open to this objection. It is prepared from raw flax of which 50 to 60 lbs. are left for twenty-four hours in a bath made up as follows: 1000 lbs. water, 20 lbs. caustic soda, 5 lbs. carbonate of soda, $3\frac{1}{2}$ lbs. soap.

This bath is boiled until the ingredients are thoroughly dissolved. After the flax is removed from the liquor it is rinsed in running water for one-half hour. This process removes the gum and resinous material from the fiber. The material is bleached with chloride of lime, being immersed for twelve to fifteen minutes or more in a bath at 120° to 140° F., made up as follows: 1000 lbs. water, 8 lbs. chloride of lime.

The material should be stirred continuously while in the bleaching liquor in order that the bleaching may be uniform. The flax is then rinsed in running water for one hour. These preliminary operations of degumming and bleaching are carried on by ordinary methods.

The last part of the process which consists in rendering the flax absorbent, is the subject of a patent [1] granted to Marin. The bleached fibers are immersed for ten minutes in the following bath: 1000 lbs. water, 100 lbs. bisulfite of soda.

The material is then extracted and rinsed in running water, after which it is immersed for fifteen to twenty minutes in a bath at 104° F., made up as follows: 1000 lbs. water, 20 lbs. sulfuric acid.

After this treatment it is rinsed in running water and treated in a bath at 140° F., made up as follows: 1000 lbs. water, 15 lbs. oxalic acid.

This last treatment lasts for about thirty minutes, during which the material is frequently agitated in order to make the treatment uniform. After rinsing and drying the flax is perfectly absorbent, silky, and lustrous.

[1] *Fr. Pat.* 453,500, April 4, 1912.

CHAPTER XXIII

JUTE, RAMIE, AND HEMP

1. The Jute Plant.—Jute is a fiber obtained from the bast of various species of *Corchorus*, growing principally in India and the East Indian Islands.[1] The most important variety is *Corchorus capsularis* or Jew's mallow, which is grown throughout tropical Asia not only as a fiber plant, but also as a vegetable. Other varieties are *C. olitorius*, *C. fuscus*, and *C. decemangulatus;* the latter two, however, yield but a small proportion of the jute fiber to be found in trade.

The commercial fiber known as Chinese jute is not a variety of jute at all, but is derived from *Abutilon avicennæ* or Indian mallow. The latter grows extensively as a weed in America.[2] The bast fiber is white and glossy, and has considerable tensile strength. It is also used for the making of paper stock. Chemically it appears to consist of bastose, and hence resembles jute in its behavior toward dyestuffs. The plant produces about 20 per-cent of fiber, but is of doubtful economic value. Another somewhat similar variety is the *Abutilon incanum*, which grows in Mexico; it is said that the Indians used the fiber from this plant for making hammocks, ropes, and nets, which are so durable that they last from seven to ten years in constant use. There are also several East Indian species, of *Abutilon*, among which may be named *A. indicum*, *A. graveolens*, *A. muticum*, and *A. polyandrum*, all of which are fiber plants suitable chiefly for cordage; the latter yields a long silky fiber resembling hemp. The *A. periplocifolium*, growing in tropical America, yields a very good bast fiber, quite long,

[1] The name "jute" is derived from the Sanskrit "jhot," meaning "to be entangled." The Bengal name of the plant is "pat" and the cloth is called "tat chotee." In the native provinces and countries, however, the names for jute are legion.

[2] Experimenters have stated that the fiber extracted from the Indian mallow before the plants have reached their full maturity is fine enough to be used in the making of carpet yarns or even finer fabrics. It takes dyes very readily, being better in this respect than jute, which is not adaptable to cheap bleaching and dyeing. The fiber was once classified in value between Italian and Manila hemp, but according to Dodge it will not grade so high, coming nearer to jute. It is stated that one acre will produce about 5 tons of the stalks, yielding 20 percent of fiber. Many experiments have been made on the cultivation of Indian mallow in the United States, especially in the Middle West and also in New Jersey, but without commercial success. The fiber is separated from the stalks by retting in water like flax of hemp, but there is a good deal of gum present which increases the difficulty of obtaining the isolated fiber.

and of a creamy yellow color. The native name is Maholtine, and the fiber may be easily stripped from the bark with no other preparation than steeping in pools of water for five to eight days. Some samples of the fiber measure 10 to 12 feet in length. A large crop may be grown per acre but there does not seem to be any regular cultivation of this plant. It is estimated that 5 tons of stripped bark may be obtained per acre and this yields from 25 to 40 percent of cleaned fiber. Most investigators of this fiber seem to think it worthy of the highest consideration.

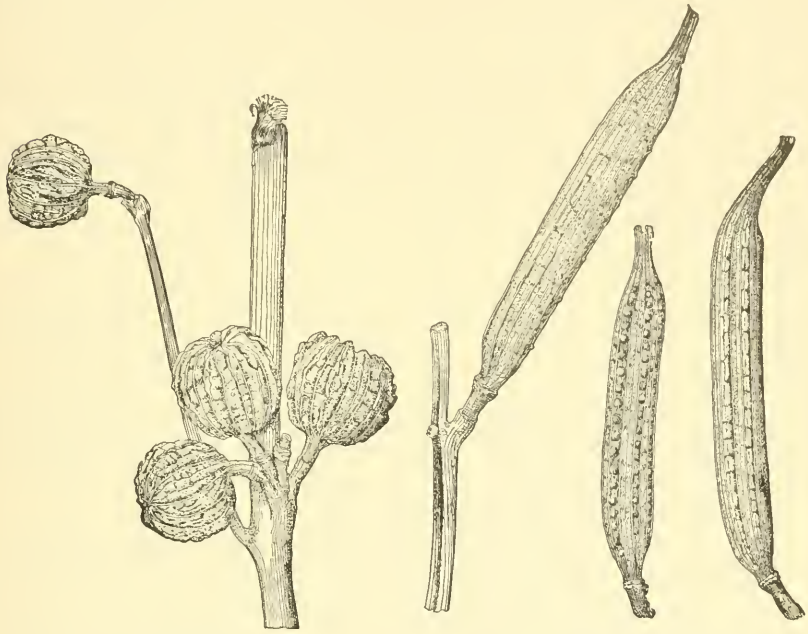


FIG. 305.—*A*, Seed-vessels of *Corchorus capsularis; B*, seed-vessels of *Corchorus olitorius*. (After *Bulletin* U. S. Dept. Agric.)

The jute plant grows to a height of from 10 to 12 feet and its fibrous layer is very thick, so that it yields from two to five times as much fiber as flax.

The *Corchorus capsularis* is an annual plant, growing from 5 to 10 feet in height, with a cylindrical stalk as thick as a man's finger, and seldom branching near the top. The leaves, which are of light green color, are from 4 to 5 ins. long by $1\frac{1}{2}$ ins. broad toward the base, but tapering upward into a long sharp point with edges cut into saw-like teeth, the two teeth next the stalk being prolonged into thistle-like points. The flowers are small and of a yellowish white color, coming out in clusters of two or three together opposite the leaves. The seed-pods are short and globular,

rough and wrinkled (Fig. 305 A). The *C. olitorius* is precisely like the former in general appearance, shape of leaves, color of flower, and habits of growth; but it differs entirely in the formation of the seed-pod, which is elongated, almost cylindrical, and of the thickness of a quill (Fig. 305 B).

2. Preparation of Fiber.—The preparation of the fiber from the jute plant is a rather simple operation. The plant is usually cut while in bloom and the stalks are freed from leaves, seed-capsules, etc., and retted by steeping in a sluggish stream of water. After a few days the bast becomes disintegrated, and the retted stalks are pressed and scutched. The fiber so obtained is remarkably pure and free from adhering woody fiber and other tissue. The prepared fiber usually has a length of from 4 to 7 ft.,[1] possesses a pale yellowish brown color, though the best qualities are pale yellowish white or silver gray, and exhibits considerable luster and tensile strength. The ends of the plant, together with the various short waste fibers, appear in trade under the name of "jute butts" or "jute cuttings," and are employed as a raw material for paper-manufacturing.

Dodge remarks on the extraction of jute that machinery has not been used for this purpose in India, the process being to ret in stagnant water assisted by the personal labor of the natives. Such a method, however, could not be operated in America or even in Europe. It would be necessary to use machines to separate the fiber from the stalk, but this method alone does not prepare the fiber in marketable form, and the decorticated ribbons of fiber would have to be retted to remove the gums and woody matters and yield a fiber capable of being spun.

According to Carter, jute is probably the most easily decorticated of any of the bast fibers. After being cut with a sickle the bundles of stems are placed in tanks or pools of stagnant water, or even in running water if more convenient. The bundles are covered with straw to protect them from the direct rays of the sun, which would make the fiber speeky. Sods are used to keep the bundles under water, but this practice is to be condemned, as the sods discolor the fiber. Logs of wood should be used in preference. The retting process usually lasts from ten to twenty days. During this time fermentation has been set up and softens the tissue in which the fiber is imbedded, and renders the gummy matter soluble until the fiber comes away quite readily from the woody portion of the stem. The stalks are examined periodically to test the progress of the retting operation, and when it is found that the fiber peels off easily, the operation is complete and the bundles are withdrawn. If under-retted, gum remains and sticks the fibers together. Over-retting makes the fiber weak and dull in color. The water used has a considerable effect upon the quality of the fiber. If steeped in clear water the fiber is of a light color, while

[1] The fiber from *C. capsularis* is generally longer than that from *C. olitorius*.

if steeped in muddy water the fiber takes a dark-gray color. Retting in running water takes longer than in stagnant water. In running water the inside bundles of the heap rot quicker than the outside bundles, producing fiber of uneven quality. The heap is therefore broken up and the inside bundles removed when ready, the outside bundles being kept for two or three days longer in the water.

Separation or stripping of the fiber from the stem must be accomplished within a couple of days of the finishing of the retting process. Standing up to the waist in the fetid water, the " raiyat " proceeds to take as many stalks as he can grasp in his hand, and with a piece of wood in his right hand to beat them flat at the end. Then he gives them a few more blows, deftly turning the bundle with the left hand meanwhile. He then breaks the bundle about 12 ins. from the end—first one way and then the other. A few more blows on the water and the boon falls out, leaving the fiber clear. He now takes hold of the separated fiber with both hands and jerks the stems backward and forward on the surface of the water. After a few jerks the fiber is cleared off the stalks. Next, after dashing the fiber repeatedly on the water to wash it and remove impurities, and wringing as much water as possible from the handful of fiber, he passes it out on to dry land to be hung out and dried in the sun. A man can thus separate about 70 lbs. (dry weight) of fiber in ten hours. The yield of fiber is only about $4\frac{1}{2}$ percent of the green weight of the stems—in fact, the yield in fiber from all the plants with which we have to deal is extremely small: Sisal, 3 to $4\frac{1}{2}$ percent; furcroya, $1\frac{3}{4}$ to $2\frac{1}{2}$ percent; sanseveria, 2 to 3 percent; phormium, 12 to 15 percent; flax, 5 percent.

3. Varieties of Jute.—Jute is often called by the name *Calcutta hemp*, owing to the fact that most of the commercial jute passes through Calcutta. It is mostly exported in the unbleached condition. The trade names for the different qualities of jute are fine, medium, common, poor, rejections, and cuttings.

Kerr [1] enumerates the following varieties of jute as being the most common in trade:

(*a*) *Uttariya*, or northern jute, by far the best variety, as it possesses the best qualities as regards length, color, and strength; it is never equal to the Desi and Deswal varieties, however, in softness. (*b*) *Deswal*, which is next in commercial value, is chiefly desirable on account of its softness, fineness, bright color, and strength. (*c*) *Desi* jute has a long, fine, soft fiber, but it has the defects of being fuzzy and of a bad color. (*d*) *Deora* jute is strong, coarse, black, and rooty, and is much overspread with runners; it is used for the manufacture of rope. (*e*) *Narainganji* jute is very good for spinning, being soft, strong, and long; but the fiber as it appears in trade has a foxy-brown color which detracts from its value, though this defect is apparently due to imperfect steeping. (*f*) *Bakrabadi* excels particularly in color and softness. (*g*) *Bhatial* jute is very coarse, but strong, and is in demand for the manufacture of

[1] *Report on Jute in Bengal*, 1874.

rope. (*h*) *Karimganji* is a fine variety, long, very strong, and of good color. (*i*) *Mirganji* is of medium quality. (*j*) *Jangipuri* jute is of short fiber, weak, and of a foxy-brown color, and not suitable for spinning.

Chaudhury gives the following glossary of Indian terms as applied to the jute fiber:

Ashmara: Weak stuff.
Batch Pat: Fiber from immature plants rejected at the time of thinning.
Bukchhal: Barky portion of the fiber at some middle places, due to plants being allowed to grow after inundation and the water has subsided.
Croppy: Fiber having rough and hard top ends.
Fui: Fiber of superior quality.
Flabby: Wanting in firmness—loose.
Ful Pat: Immature stuff cut before flowering. This fiber is excellent in color, but somewhat weak and gummy.
Knotty: Full of knots. Knot is a portion of fiber agglutinated which resists separation; mainly due to an insect bite or puncture on the growing plant.
Mossy: The lowland swamped jute with numerous adventitious roots (or extraneous vegetable matter).
Rooty: The jute is called by this name if from the lower part of the fiber the gum and bark are not wholly removed, and in which the fibers stick together.
Specky: Containing patches of outer bark here and there.
Sticky: With pieces of stick or pith among the fiber (usually in small plants from the Daisee district).

4. Microscopy of Jute.—According to Höhnel, the bast-cells of the jute fiber are from 1.5 to 5 mm. in length, and from 20 to 25 microns in thickness, the mean ratio of the length to the breadth being about 90; consequently the elements of the jute fiber are relatively short. In cross-section the jute fiber shows a bundle of several elements bound together; these are more or less polygonal in outline, with sharply defined angles. Between the separate elements is a narrow median layer (Figs. 306 and 307), which, however, does not give a much darker color with iodine and sulfuric acid than the cell-wall itself. The lumen is about as wide, or at

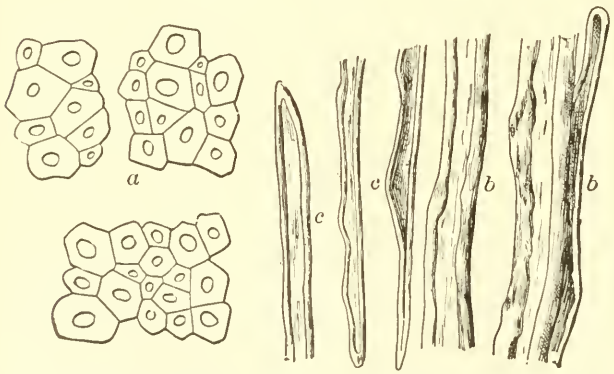


FIG. 306.—Jute Fiber. (×300.) *a*, Cross-sections; *b*, longitudinal views; *c*, ends. (Cross and Bevan.)

times even wider, than the cell-wall, and in cross-section is round or oval. Longitudinally the lumen shows remarkable constrictions or irregular thicknesses in the cell-wall (Fig. 308); though toward the end of the fiber the lumen broadens out considerably, causing the cell-wall to become very thin. Externally the fiber is smooth and lustrous, and has no jointed ridges or transverse markings, such as seen in linen or most other bast fibers.

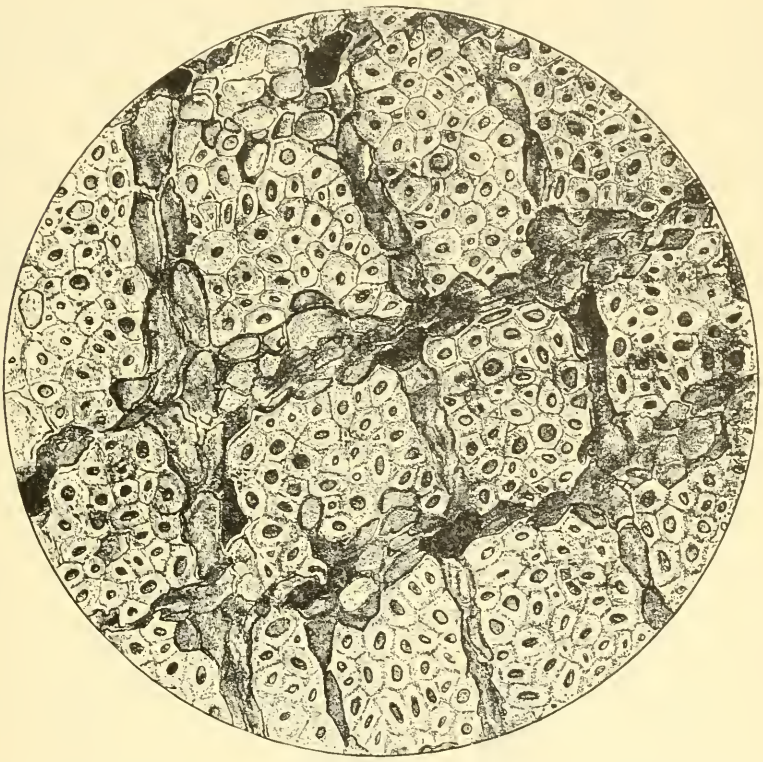


Fig. 307.—Cross-section of Jute Straw. Showing transverse section of portion of bast only, giving the anatomy of the fibrous tissue, the form of the bast-cells, and the thickening of the cell-walls. (Cross and Bevan.)

Müller gives the following method for the isolation of pure cellulose from jute: 2 grams of the material are dried at from 110° to 115° C. In order to remove wax, etc., it is next treated with a mixture of alcohol and benzol, and is subsequently boiled with very dilute ammonia water. The softened mass is then pulverised in a mortar, and placed in a large, glass-stoppered flask with 100 cc. of water. From 5 to 10 cc. of a solution of 2 cc. of bromine in 500 cc. of water are added until a permanent yellow

is obtained after standing twelve to twenty-four hours. The substance is then filtered, washed with water, and heated to boiling with water containing a little ammonia. After this it is filtered, washed, and again treated with the bromine solution, as above indicated, until a permanent yellow color is obtained. The fiber is then boiled with dilute ammonia, and on filtering and washing leaves a residue of pure white cellulose.

Fig. 308.—Jute Fiber. (×300.) (Micrograph by author.)

5. Chemical Properties of Jute.—In its chemical composition jute is apparently quite different from linen and cotton, being composed of a modified form of cellulose known as lignocellulose or bastose. Bastose, properly speaking, is a compound of cellulose with lignin. It behaves quite differently from cellulose toward various reagents, its chief distinction being that it is colored yellow by iodine and sulfuric acid, whereas pure cellulose is colored blue. With dilute chromic acid, to which a little hydrochloric acid has been added, jute gives a blue color. When treated with an ammoniacal solution of copper oxide the fibers swell considerably, but do not readily dissolve. With chlor-iodide

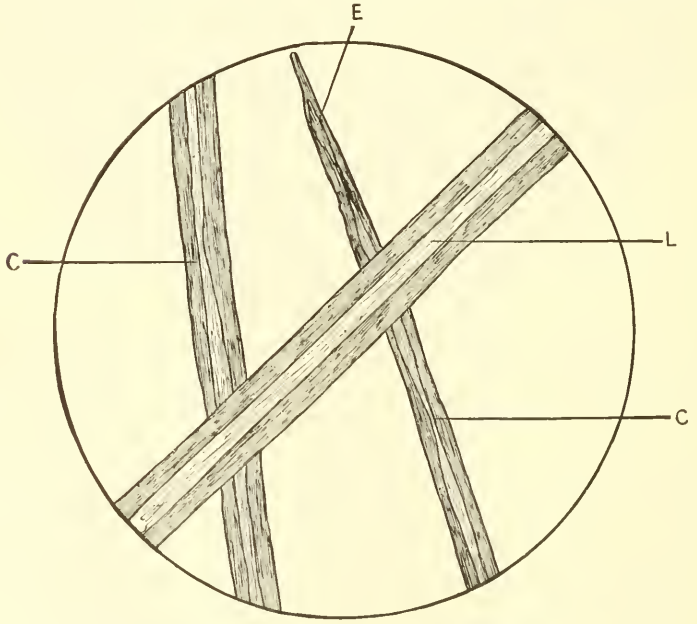


Fig. 309.—Jute Fiber. (×300.) *L*, Lumen; *C*, constrictions in lumen; *E*, end of fiber. (Micrograph by author.)

of zinc jute gives a yellow color. The following table gives the principal reactions used to distinguish cellulose from bastose:[1]

Reagent.	Cellulose.	Bastose.
Iodine and sulfuric acid	Blue color	Yellow to brown color
Aniline sulfate and sulfuric acid.	No change	Deep-yellow color
Basic dyestuffs	No change	Becomes colored
Weak oxidising agents	No change	Quickly decomposes
Schweitzer's reagent	Quickly dissolves	Swells, becomes blue, and slowly dissolves

A solution of ferric ferricyanide[2] colors ligno-cellulose a deep blue, owing to the deoxidation of the ferric compound by the lignone. This reaction is useful in following the progressive elimination of the lignone constituents in the isolation of pure cellulose from jute, etc.

The chief chemical difference between jute and the pure cellulose fibers is in the ability of the former to combine directly with basic dyestuffs. In fact it acts in this respect similar to cotton which has been mordanted with tannic acid. Jute is also more sensitive to the action of chemicals in general than cotton or linen. On this account it cannot be bleached with much success, as treatment with alkalies and bleaching powder weakens and disintegrates the fiber to a considerable extent. Schoop recommends boiling jute in a soap solution for the purpose of cleaning and preparing it for bleaching or dyeing; the strength of the fiber is but little diminished and the luster is improved, also the fiber is made soft and pliable. The use of sodium silicate, soda ash or caustic soda is not to be recommended. Lime water makes the fiber brittle, while ammonia gives it a harsh feel and injures the luster.

It must be borne in mind that the jute fiber is a lignocellulose composed of cellulose units about $\frac{1}{8}$ in. in length cemented together by lignone components. In bleaching processes where a full white is obtained, these lignone substances are removed and this leads to the structural disintegration of the fiber.

When jute is hydrolysed by heating with 1 percent sulfuric acid in

[1] According to Cross and Bevan, the jute fiber may be regarded as an anhydro-aggregate of three separate compounds: (*a*) A dextrocellulose allied to cotton, (*b*) a pentacellulose yielding furfural and acetic acid on hydrolysis; (*c*) lignone, a quinone which is converted by chlorination and reduction into derivatives of the trihydric phenols.

[2] This is the green solution resulting from the interaction of solutions of ferric chloride and potassium ferricyanide.

an autoclave to 110° C. small quantities of formic and acetic acids are produced. Under similar conditions cotton does not yield these acids. Cross [1] consequently considers that the ligno-cellulose molecule contains formyl and acetyl groups.

The jute fiber is relatively weak when compared with other bast fibers, and the chief reasons for its prominence among the textile fibers are its fineness, silk-like luster and adaptability for spinning. It is also a relatively soft fiber, differing in this respect from the coarse cordage fibers. In India the natives weave it into mats and a coarse cloth for fabrics. The plant is also easy to cultivate, and returns a large yield of fiber. The chief defect of jute is its lack of durability; when exposed to dampness it rapidly deteriorates; and even under ordinary conditions of wear, the fiber gradually becomes brittle and loses much of its strength. Owing to these defects jute cannot be used successfully to substitute Manila hemp or sisal in the making of rope or binder twine. The bleached fiber is especially liable to such deterioration; it gradually loses its whiteness, and, evidently due to oxidation, becomes dingy and yellowish brown in color.

Samples of jute fiber exposed for two hours to steam at 2 atmospheres, followed by boiling in water for three hours, and again steamed for four hours, lost 21.39 percent by weight, being about three times as great a loss as that suffered by hemp, Manila hemp, phormium, and coir. A similar test for jute with flax hemp, ramie, and other fibers showed as great a loss, while flax lost less than 4 percent and ramie a small fraction under 1 percent. Contrary to the statements of Cross and Bevan that the jute fiber is completely decomposed by heating with water or steam to 120° to 130° C. Schoop has observed that only a slight decomposition sets in at 250° to 300° C.; in other words jute is as resistant towards hot water as either linen or hemp.

6. Analysis of Jute.—Analysis of jute shows it to consist of the following:

Constituents.	Nearly Colorless Specimen, Percent.	Fawn-colored Fiber, Percent.	Brown Cuttings, Percent.
Ash	0.68		
Water (hygroscopic)	9.93	9.64	12.58
Aqueous extract	1.03	1.63	3.94
Fat and wax	0.39	0.32	0.45
Cellulose	64.24	63.05	61.74
Incrusting and pectin matters	24.41	25.36	21.29

[1] *Berichte*, 1910, p. 1526.

The ash of jute consists principally of silica, lime, and phosphoric acid; manganese is nearly always present in small amount. The ash in completely dry jute varies from 0.9 to 1.75 percent.

According to Wiesner, fresh jute contains about 6 percent of hygroscopic moisture and brown jute about 7 percent. When completely saturated with moisture the former will contain about 23 percent and the latter 24 percent. The Turin Congress adopted a regain of $13\frac{3}{4}$ percent for the conditioning of jute.

Dubosc [1] gives the following example of an analysis of jute:

(1) *Estimation of total lime.*—The jute is treated for forty-eight hours with a 4 percent solution of pure hydrochloric acid, and the lime (originally present as free lime or pectate of lime) is thrown down by ammonium oxalate; 22 grams of jute gave 1.837 grams of lime. (2) *Estimation of pectic acid.*—The jute after being treated with hydrochloric acid, is washed and macerated for forty-eight hours with a 2 percent solution of caustic soda; filter, wash, and add the washings to the filtrate, which is colored red in consequence of the presence of sodium pectate. The pectic acid is thrown by hydrochloric acid, and weighed; the sample gave 5.455 grams of pectic acid, which would correspond to 0.673 gram of lime combined as calcium pectate. The amount of free lime therefore is equal to 1.164 grams. (3) *Estimation of pectose.*—The jute freed from lime and pectates is treated for two hours with a boiling 2 percent solution of hydrochloric acid. The pectose is thereby converted into pectin, which precipitated by alcohol; the sample gave 0.05 percent of pectose. (4) *Estimation of cellulose.*—The jute remaining from the previous treatments is treated for eight days with an ammoniacal copper solution (as concentrated as possible), and filtered with a suction pump through asbestos. Wash with ammoniacal copper solution, and precipitate the cellulose from the filtrate with very dilute hydrochloric acid; the sample gave 50 percent of cellulose. (5) *Estimation of paracellulose.*—The residue from the last determination is treated for an hour at 100° C. with hydrochloric acid, which renders the paracellulose soluble in ammoniacal copper solution. The treated residue is therefore extracted with this reagent, and precipitated from the filtrate with hydrochloric acid; the sample gave 11.4 percent of cellulose. (6) *Estimation of cutose.*—The residue is treated with dilute caustic potash at 100° C., in which the cutose is soluble. From the filtrate it is precipitated with sulfuric acid; the sample gave 2.00 percent of cutose. (7) *Estimation of vasculose.*—The residue from the previous treatment is treated for one hour with dilute nitric acid, washed, and then macerated with a dilute soda solution. From the dark brown filtrate the vasculose is precipitated with hydrochloric acid; the sample gave 20.5 percent of vasculose. (8) *Estimation of metacellulose.*—The residue is washed and gives by difference the amount of metacellulose. (9) *Estimation of fats.*—The jute is macerated for eight days with petroleum spirit, and the light yellow filtrate evaporated to dryness. (10) *Estimation of gums.*—The residue from the fat extraction is further extracted successively with ether and then with alcohol, and the extracts evaporated and weighed. (11) *Estimation of soluble pectates.*—Besides calcium pectate jute also contains pectates soluble in water. To determine these, the jute remaining after the previous two estimations is extracted in a closed vessel with distilled water for fourteen days. In the filtrate the soluble pectates are precipitated with alcohol and weighed.

[1] *Bull. Soc. Ind. Mulh.*, 1903.

The sample of jute in the above analysis gave the following results:

	Percent.
Fatty substances	0.049
Gums soluble in ether	1.600
Gums soluble in alcohol	0.637
Pectates soluble in water	1.272
Pectate of lime	6.128
Lime	1.104
Pectose	0.050
Cellulose	50.000
Paracellulose	11.400
Metacellulose	5.200
Cutose	2.000
Vasculose	20.500

7. Uses of Jute.—Jute is principally used for the making of coarse woven fabrics, such as gunny sacks and bagging, where cheapness is of more consequence than durability. It also finds considerable use in the tapestry trade, being used as a binding-thread in the weaving of carpets and rugs. On account of its high luster and fineness, it is also adapted for the preparation of cheap pile fabrics for use in upholstery. Of late years a variety of novelty fabrics for dress goods have also been made from jute, used in conjunction with woolen yarns.

Jute has also been used extensively as a substitute for hemp, for which purpose the former is rendered very soft and pliable by treatment with water and oil. A mixture of 20 parts of water with 2.5 parts of train-oil is sprinkled over 100 parts of jute fiber. It is left for one to two days, then squeezed and heckled, whereby the fibers become very soft and isolated. Jute is also largely used in the manufacture of twine, window cord, and smaller sizes of rope. Owing to its cheapness, it is used to adulterate other more valuable fibers, but due to its tendency to rapid deterioration, its use in this connection should not be encouraged. The "jute butts" and miscellaneous waste are extensively employed as a raw material in the manufacture of paper.

Jute is the cheapest fiber used in textile manufacturing, and it is employed in greater quantities than any other except cotton. All the jute of commerce comes from India, and until recent years, Scotch and Indian mills supplied practically all the manufactured jute appearing in international trade. The coarse, loosely woven cloth used in baling cotton is about the only jute fabric woven in this country. Though America uses each year several hundred million jute bags for the shipment of its raw products, these bags are made from imported burlap. The United States each year pays for jute bags and burlap a considerably greater sum than that paid for the combined imports of all piece-goods of wool, silk, cotton, flax, and hemp; in fact, for the year 1919 it was more than twice as great.

The waste arising in the spinning of jute mixed with similar waste from linen and hemp is manufactured into a product known as *Kosmos fiber* or *artificial wool.*

By treatment with strong caustic soda solutions (36° to 40° Bé.) jute is converted into a woolly sort of fiber.[1] Jute is much more sensitive toward acids than either linen or hemp; concentrated mineral acids readily dissolve the fiber; dilute mineral acids even as minute traces left in the fiber, quickly rot it. Sulfurous acid and sodium bisulfite are without bad effect, and the same is also true of the organic acids. Chloride of lime and neutral hypochlorite of soda are used for bleaching jute.

Some unusual results were obtained during the War with jute by the Deutsche Faserstoff-Gesellschaft. By a special process of chemical treatment a long, fine, and beautiful fiber was produced therefrom, a fiber which can readily be spun on the worsted system, pure or mixed with wool. Shoddy made from old jute rags can also be spun on the worsted or woolen system. Serges made from old jute rags or cloth made from half wool and half jute, wool or piece dyed, were used for women's costumes, overcoating, etc. Furthermore, sweaters and vests were made from all jute worsted yarn, and it has been difficult to recognise them as being made of such. The Deutsche Faserstoff-Gesellschaft claims that jute represents the cheapest fiber suitable for worsted yarn that has been discovered.

8. Statistics of Jute.—Jute was first introduced into Europe about the year 1795. It has been used for spinning since 1830. At the present time there is more jute used, weight for weight, than any other textile fiber with the exception of cotton. Calcutta is the center of the jute industry and through this market the rest of the world draws its supply of either the raw jute fiber or manufactured jute products. The manufacture of jute bags has been developed in India to a surprising extent, and these bags or "gunny sacks" as they are generally called, which formerly were made in Europe are practically all marketed now from Calcutta. The following table shows the number of jute bags exported from Calcutta in the year 1920:

Exported to	No. of Bags.
Great Britain	48,000,000
Belgium	15,600,000
France	13,800,000
Egypt	13,000,000
Chile and Peru	59,400,000
Cuba	22,500,000
United States	71,800,000
Japan	13,800,000
China	32,400,000
Java	24,600,000
Cochin China	12,400,000
Australia	34,100,000

[1] See *Färb. Zeit.*, 1900, p. 325.

The production of jute since 1915 has been falling off, as shown by the following table:

ACREAGE AND PRODUCTION OF JUTE

Year.	Acreage.	Production, 400-lb. Bales.	Equivalent, in Gross Tons.	Bales per Acre.
1909–13 (5-year average)	2,949,600	7,905,380	1,411,675	2.68
1914	3,169,600	8,751,800	1,562,821	2.76
1915	3,358,700	10,443,900	1,864,982	3.11
1916	2,377,300	7,428,700	1,326,554	3.12
1917	2,671,850	8,305,600	1,483,143	3.11
1918	2,500,382	7,019,088	1,253,409	2.81
1919	2,821,575	8,486,234	1,515,399	3.01
1920	2,508,773	5,978,592	1,067,606	2.38
1921	1,518,358	4,052,609	723,680	2.67
1922	1,456,806	4,236,828	756,596	2.91

The largest consumers of Indian jute are the Calcutta mills, which take approximately half of the total crop, but the United States and European countries import large quantities. The following table shows the exports of jute from British India to various countries:

	1910–14. (5-year Average).	1920.	1921.	1922.	1923, (April to Nov.)
	(In Gross Tons.)				
United Kingdom	301,864	310,670	136,023	90,835	112,945
Germany	164,392	3,609	72,068	144,013	95,263
United States	95,621	77,649	110,005	66,422	58,626
France	76,507	80,731	50,044	55,837	39,824
Italy	38,109	28,076	22,869	25,325	22,226
Spain	21,764	19,138	23,857	22,120	19,329
Others	66,131	71,941	57,548	63,133	44,861
Total	764,388	591,814	472,414	467,685	393,074

Raw jute imports into the United States, however, are of minor importance compared with the imports of burlap, the principal product manufactured from jute. Imports of burlap each year are several times as great in value as the imports of raw jute. The following table shows the imports into the United States of raw jute, jute butts, jute bags and fabrics:

Imports of Jute and Jute Products into the United States

Year.	Jute and Jute Butts, Tons.	Jute Bags, Pounds.	Jute Fabrics, Pounds.
1909–13 (5-year average)	103,294	47,944,000	389,644,000
1919	62,332	46,216,000	446,056,000
1920	96,039	51,427,000	571,534,000
1921	62,416	65,250,000	475,141,000
1922 (to September 21)	49,861	41,144,015	376,792,105

The greater part of the raw jute imported into the United States is consumed in the manufacture of the heavy coarse wrapping known as cotton bagging, used for covering raw cotton. About 90,000,000 yards of this fabric are required annually to cover the cotton crop of the country, and of this amount, practically all is manufactured in the United States. On the other hand, in spite of the fact that the United States is the world's largest consumer of burlap, the American production of burlap is insignificant.

Production of Jute Goods in the United States in 1914

	Production.	Value.
Bags and bagging, square yards	131,827,658	$ 6,441,000
Rope, pounds	26,814,920	2,097,000
Twine, pounds	55,282,159	5,268,000
Yarn, pounds	69,827,005	7,358,000
Carpets and rugs, square yards	4,862,302	1,172,000
Total	.....	$22,336,000

Price of Jute in New York (Cents per Pound)

1913	6.6	1917	10.5
1914	7.5	1918	13.0
1915	5.1	1919	9.3
1916	7.5	1920	11.0

9. Lignocellulose.—Jute differs somewhat from the previously considered vegetable fibers in that it does not consist of comparatively pure cellulose, but contains a large amount of modified cellulose known as lignocellulose. As this latter compound differs essentially both in its chemical composition and reactions from ordinary cellulose, it will be of immediate

interest to make a study of this product, not only in connection with its direct association with jute, but also as a general substance occurring in other vegetable fibers as well. It is doubtful if lignocellulose can be regarded as a simple chemical body, its reactions tending to indicate that it is a complex of several different bodies. The lignocellulose of jute has a lower percentage of oxygen than that present in normal cellulose, as follows:

	Normal Cellulose (Cotton), Percent.	Lignocellulose (Jute), Percent.
Carbon	44.2	46–47
Hydrogen	6.3	6.1– 5.8
Oxygen	49.5	47.9–47.2

There are two distinct chemical differences between normal cellulose and lignocellulose: (1) Normal cellulose does not react with chlorine, whereas lignocellulose readily combines with chlorine to yield definite products; (2) normal cellulose does not yield furfural whereas lignocellulose does, thereby indicating the possibility of its containing an oxycellulose derivative.

The formation of lignocellulose is to be considered as a process of thickening by incrustation, and recent researches in this matter indicate this incrustation is a process of forming adsorption compounds; the colloidal hydrated celluloses at first elaborated taking up soluble colloidal products from solution in the cambium fluids.[1] Chemically the formation of lignin is to be regarded as a combination of cellulose with acid and unsaturated ketonic groups. Conversely, processes which attack these groups resolve the lignin into soluble derivatives and cellulose which is resistant and insoluble. The separation of the cellulose is attended by disintegration, and the fiber is resolved into its component cell units, which are usually 2 to 3 mm. in length and 0.02 to 0.03 mm. in diameter. The elimination of the non-cellulose constituents is also attended by considerable loss in weight. In jute the amount of cellulose is about 70 to 80 percent, and the lignone about 30 to 20 percent.

Lignone reacts quantitatively with chlorine combining in a characteristic and invariable proportion. In the case of jute this proportion is 8 percent of the lignocellulose. The cellulose and lignocellulose in jute and similar fibers may be separated by a treatment with chlorine the lignocellulose combining with chlorine to yield a product soluble in a solution of sodium bisulfite. Cross and Bevan described the following method of procedure. A weighed amount (5 grams) of the fiber is dried

[1] Wislicenus, *Zeitschr. Kolloide*, 1910, p. 17.

in a water-oven, and then boiled with a 1 percent solution of caustic soda for thirty minutes. The mass is then removed, and after pressing out most of the liquid it retains, it is treated with a current of chlorine gas for one-half to one hour. It is then washed and slowly heated with a 2 percent solution of sodium bisulfite. When the liquid reaches the boiling point, 0.2 percent of caustic soda is added, and the boiling allowed to proceed for five minutes. The residue consists of nearly pure cellulose. It is washed with hot water and further purified by a few minutes' treatment with a 0.1 percent solution of potassium permanganate, again washed, dried, and weighed. Bromine cannot be used in this reaction in place of chlorine as it acts on the cellulose to some extent, giving a figure for lignocellulose from 2 to 5 percent higher.

The furfural reaction of lignocellulose is obtained by heating jute with dilute hydrochloric acid. Cross and Bevan give the following method of estimating furfural in jute: A weighed portion (5 grams) of the fiber is heated with 100 cc. of a 12 percent solution of hydrochloric acid in a flask connected with a condenser and the tube of a stoppered separatory funnel. The distillation should proceed at the rate of 2 cc. per minute, and successive portions of 30 cc. each collected until aniline acetate and hydrochloric acid no longer yield a rose coloration. The distillate is then treated with a slight excess of sodium carbonate, then acidified with acetic acid, and made up to a definite volume with sodium chloride solution containing approximately the same amount of salt as has been formed in the distillate. It is next treated with an aqueous solution of phenylhydrazine containing 12 grams of the latter and 7.5 grams of acetic acid in 100 cc. The precipitated hydrazone is washed, dried in a vacuum at 70° C., and weighed. This weight multiplied by the factor 0.538 gives the amount of furfural.

Lignocellulose also reacts with several aromatic compounds to give colored bodies. With phloroglucinol and hydrochloric acid it gives a crimson color, with phenylhydrazine a yellow color, and with a dimethyl-paraphenylenediamine a crimson color.

Cross, Bevan and Briggs [1] have shown that there is a definite absorption of phloroglucinol by lignocellulose, and the following method has been suggested by them for determining this absorption: A weighed quantity (2 grams) of the dried fiber is mixed with 40 cc. of a solution of 2.5 grams of phloroglucinol in 100 cc. of hydrochloric acid (specific gravity 1.06). After standing for twelve hours the liquid is filtered through cotton; 10 cc. of the filtrate are then titrated with a standard solution of formaldehyde, and the difference between the result and a blank titration on 10 cc. of the original phloroglucinol solution gives the measure of the absorption. The standard solution for the titration contains 2 grams of 40 percent

[1] *Chem. Zeit.*, 1907, p. 725.

formaldehyde mixed with 500 cc. of hydrochloric acid (specific gravity 1.06). The 10 cc. of phloroglucinol solution are diluted with 20 cc. of the hydrochloric acid and heated to 70° C., and the aldehyde solution is added at the rate of 1 cc. every two minutes until all the phloroglucinol has been precipitated, and the liquid no longer gives a red coloration when dropped on paper containing ground wool pulp (newspaper). This test yielded the following figures for phloroglucinol absorption:

Material.	Phloroglucinol Absorbed, Percent.
Wood pulp	7.5
Jute	4.2
Esparto cellulose	0.5
Cotton	0.2

Lignocellulose also reacts with the bisulfites of the alkali and alkaline earth metals; at elevated temperatures and under pressure being converted quantitatively into cellulose and soluble sulfonated products of lignone. On this reaction is based the manufacture of wood-pulp by the sulfite process. Solutions of caustic soda at elevated temperatures also attack lignocellulose, separating the cellulose and giving ill-defined soluble products of lignone. On this reaction is based the manufacture of soda-pulp.

Hydriodic acid reacts with lignocelluloses with formation of methyl iodide. The estimation of this latter volatile product is taken as the index or quantitative measure of the "methoxy" (OCH_3) groups present in the lignocellulose. This index may also be considered as the "chemical constant of lignification." The following table shows these constants as determined for various fibers:

	Percent, OCH_3.
Jute	1.87
Cotton	0.0
Flax	0.0
Hemp	0.29
China grass	0.07
Sulfite pulp	0.34
Swedish filter-paper	0.0

10. Ramie or China Grass.—This is a fiber obtained from the bast of the stingless nettle, or *Bœhmeria*. Although frequently confounded in trade, ramie and China grass are in reality two distinct fibers. The former (also known as rhea) is obtained from the *Bœhmeria tenacissima*, which grows best in tropical and subtropical countries. The latter is obtained from *Bœhmeria nivea*, which grows principally in the more temperate climes.

The term ramie or rhea was apparently derived from a term in use by the inhabitants of the Malay Archipelago, and was first brought into European usage by the Dutch. During recent years the supposed distinction between China grass and ramie has been practically set aside. As far as the plants themselves are concerned, however, some distinction is still preserved; the ramie is said to yield stronger fibers and is often called *green ramie*, as the leaves of the plant are quite green in color; the other plant is often called *white ramie* because its leaves have a mother-of-pearl whiteness on the under side.

The ramie plant is of more robust habit and has larger leaves, which are green on both sides. The China grass plant has leaves which are white felted beneath. The two species, however, are so similar in nature, and the fibers are so universally confounded with one another, that it is only possible to consider them as a single substance, which will be done under the name of ramie. There has been some discussion as to the botanical classification of true ramie. Formerly the old China grass plant was classed along with the stinging nettles (*Urtica*), but in more recent years this opinion has been revised and now both China grass and ramie are ascribed to the class of stingless or so-called "shooting" nettles (*Bœhmeria*). The stinging nettles are very common plants and are found distributed very widely in most countries of the world. They are characterised by the possession of fine stinging hairs, while the *Bœhmeria* species are deficient in this feature. The common stinging nettle of Europe (*Urtica dioica*) has been utilised from very early times for the preparation of fish lines on account of the great strength of the fiber obtained from it. Savorgnan states that it is known as Swedish hemp and that the plant has long been actively cultivated in Sweden for the production of fiber employed in the making of cordage and sail cloth.

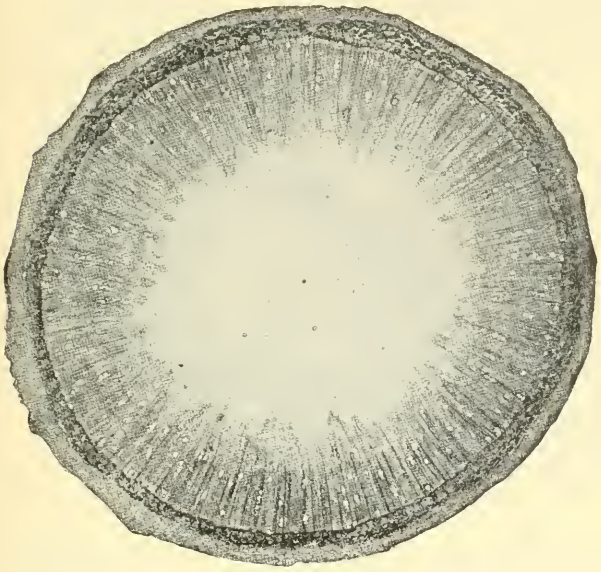


FIG. 310.—Cross-section of Ramie Stalk.

The plant is a snrub, reaching 4 to 6 ft. in height, and is very hardy. It is cultivated largely in China [1] and India, and has also been grown successfully in America.[2]

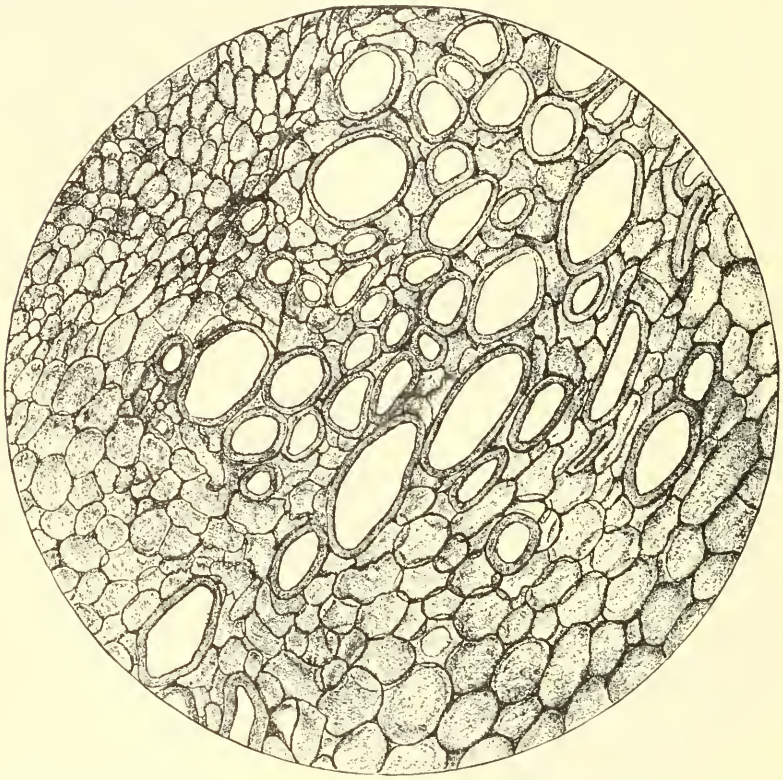


Fig. 311.—Cross-section of Ramie Straw. Showing transverse section of bast region only; the bast fibers are to be distinguished by their large area from the adjacent tissue. (Cross and Bevan.)

[1] The ramie plant in China is known as *Tchow Ma*, and is extensively cultivated for its fiber. From 8000 to 10,000 tons of fiber annually are exported to Europe, which received most of its supply from this source. In Cochin China ramie is known as *Cay-gai*, in Bengal, as *Kankura*. Ramie is also grown in Malay, though the Malayan plant exhibits certain marked differences from the Chinese type, and is usually regarded as a distinct variety.

[2] There seems to be only one American representative of the stingless nettle (the *Bæhmeria cylindrica*); it is also known as the *false nettle* and is to be found as a sort of weed growing on the waste lands extending from Ontario and Minnesota to Florida and Kansas. It has no value, however, as a fiber-producing plant, so does not possess any economic importance. There is another somewhat similar plant found in the Sandwich Islands (*Bæhmeria stipularis*) and it is of some interest as it is used to a slight extent by the natives for the preparation of their *kapa*. It is interesting to note in this connection that in the United States there are apparently several varieties

The use of China grass or ramie was probably known to the Chinese at a very early period; some writers have also attempted to show that it was used in Egypt several thousand years ago contemporaneously with flax for the preparation of mummy-cloths.[1]

Dr. Watt is of the opinion that ramie dates back to great antiquity in India. He states that frequent reference is made in the Ramagana to a garment called *kshauma*, and says that while this word is generally regarded as a name for linen, it so strongly resembles the Chinese name for ramie that there is undoubtedly some connection between the two.

Ramie is grown in almost unlimited quantities throughout equatorial Africa, India and China, though the best qualities come from the last country. In China ramie grows wild in large quantities, though it is also cultivated in small plots by the peasants. It is stated that as far as the actual supply of the plant is concerned, the quantity appears to be far in excess of any possible requirements.

11. Properties of Ramie Fiber.—The fiber of ramie is very strong and durable, probably ranking first of all vegetable fibers in this respect. It is also the least affected by moisture. It has three times the strength of hemp, and the fibers can be separated to almost the fineness of silk.

Ramie also has the special advantage of not rotting when exposed to weather conditions or when immersed in water. It also takes dyestuffs rather readily, though in this respect it is harder to completely penetrate the fiber than is the case with cotton.

The fiber of ramie is exceptionally white in color, being almost comparable to bleached cotton in this respect, and does not appear to have any natural coloring matter at all. It also has a high luster, excelling linen in this respect.

From experiments made on the tensile strength of isolated filaments of ramie, it appears that this fiber has a breaking strain of from 17 to 18 grams. Ramie degummed in the laboratory of Frémy showed a breaking strain of from 21 to 22 grams, and by very careful degumming it has been possible to attain a strength of from 35 to 40 grams. Isolated fibers of hemp show a breaking strain of only 5 grams.

Cottonised ramie is fiber on which the degumming process has been carried too far, with the result that the individual filaments have been

of stinging nettles as indigenous plants. The Indians were acquainted with its use for fiber purposes, and employed it in the making of bowstrings and twine on account of its great strength and durability. There is a very good sample of this American fiber in the Botanical Museum of Harvard University.

[1] By some authorities it is claimed that ramie was the fiber from which the ancient Egyptian mummy cloths were made, rather than from flax. This view is supported by the fact that flax does not grow in hot climates.

more or less separated into their elements; the fiber is white, but without the characteristic transparency and luster of ordinary ramie.[1]

The brilliant and transparent fabrics known in China as *A-pou* and sold in England under the name of *grass cloth* are made from ramie.

Ramie is used to some extent in the preparation of a fiber which may be classed as a *wool substitute*. The ramie is specially prepared for this purpose and gives a yarn somewhat resembling wool in appearance and quality. The Stycos fiber marketed to some extent in the United States is a product of this character. It closely resembles the Solidonia fiber used in Europe for the same purpose. It can be used alone or mixed with wool before carding or afterward in the drawing operations of preparing the yarn.

The following table gives the chief physical factors of the ramie fiber in comparison with the other principal fibers:

	Ramie.	Hemp.	Flax.	Silk.	Cotton.
Tensile strength	100	36	25	13	12
Elasticity	100	75	66	400	100
Torsion	100	95	80	600	400

12. Preparation of Ramie.—Having such excellent qualities as a fiber, it would be natural that ramie should have had considerable attention bestowed upon it. The two main stages in the preparation of the fiber for spinning are decorticating and degumming. As brought into America and Europe for use in spinning, ramie is always in the decorticated condition and requires simply to pass through a degumming operation. The chief difficulty in the way of its universal and widespread adoption has been the lack of an efficient process for properly decorticating the fiber from the rest of the plant. In China and India, where this fiber has long been employed for the weaving of the finest and most beautiful fabrics, the decortication of the fiber is carried out by hand, the stems being soaked in water and the bark scraped off by the natives. In China a native can

[1] A recent French patent describes the following process for preparing imitation wool from ramie: 100 kilos. of stripped ramie are cut into lengths of 30 to 80 mm. and boiled for two hours in 1000 liters of a 2½ percent solution of sodium carbonate. The liquor is then run off, and the material is again boiled for 6 hours in 1000 liters of water to which has been added 20 liters of caustic soda of 36° Bé. After draining and washing thoroughly with cold water the scoured fiber is hydro-extracted, dried, opened, and next curled by working it for one hour in a cold bath containing 1000 liters of water and 1000 liters of caustic soda of 36° Bé. The excess of the solution is then pressed from the wet fiber, and the process is completed by the operations of souring, washing, drying, and carding.

produce about 8 lbs. of cleaned ramie per day.[1] This, of course, would be impracticable in western countries.

The chief and perhaps the only reason that ramie has not maintained its position as a fiber plant is the fact that it is very difficult to isolate the fiber proper from the rest of the plant tissues, and as this can only be done up to the present time by hand labor, it is not feasible under the present-day conditions to produce the ramie fiber in a sufficiently economical manner to make it available for industrial uses in competition with linen and still less with cotton. In ancient times there is no doubt that all the bast fibers employed for spinning and weaving were produced by hand operations, and therefore ramie under these conditions was not any more difficult to obtain than the other fibers.

Ramie has been found in the composition of hand-woven fabrics in various mummy cases in Egyptian tombs, dating as far back as the fifteenth dynasty; but rather curiously, this fiber then seems to drop out of Egyptian industry as it does not occur in the later textile fabrics, being replaced by linen. The first recognition of ramie was in Chinese fabrics imported into Europe, and in England these were generally known as China grass cloth. In Germany the fabrics were known as nettle cloth (nessel tuch), though there is a little confusion in origins to be found in this connection. This was due to the fact that the Romans apparently were acquainted with the ramie fiber (Virgil in his second song on agriculture evidently refers to this fiber) and in the dissemination of the Roman culture throughout Europe no doubt this knowledge of ramie was carried to Germany and other European countries as they developed industrially. The fiber, however, that was employed in Germany seems to have been principally derived from the nettle plant of considerable divergence from the oriental ramie. This nettle bast fiber has always been more or less utilised in Germany, though after cotton became the predominating factor in the class of vegetable fibers, the nettle fiber rapidly declined in importance. On this account there has always been a kind of confusion in the designation of ramie and nettle fiber.

In India and the Himalayan districts ramie has also been in use from prehistoric times. In early Sanscrit literature it is often to be met with under the name of grass linen; this term, of course, being the English translation, though the character of the material described in the Sanscrit indicates reference to the ramie and not to what we now know as linen. In such poems as the Ramazana and the Kalidassa there are frequent references to be found to the plant and the fiber and the corresponding

[1] For detailed descriptions of the methods employed in China and India for the preparation of ramie, see *Three Years in Western China*, by Sir Alex. Hosie; also *The Journal of the Agricultural and Horticultural Society of India*, vol. 9, part 1, Calcutta, 1891, and recent issues of *Indian Industries and Power*.

fabrics made therefrom, which are no doubt the ancient ramie. The early peoples of southern Russia carried on the knowledge of ramie, probably deriving it from the peoples of the Himalayan districts. Anyway, according to the Chronicles of Nestor (written about A.D. 904) the sails of the ships on the Volga were made of ramie or China grass.

The French have long shown a special interest in the development of ramie as a textile fiber in Europe, and they have been very energetic in cultivating the plant in their various colonies. The proper development of its use, however, as a textile fiber has not been commensurate with its esteemed and valuable qualities, and this has been due, as before indicated, to the impossibility so far of cheaply and efficiently obtaining the fiber from the plant, in other words of decorticating it.

In Europe attempts have been made to decorticate ramie by mechanical means. A rather successful process of this type is described by Glafey,[1] the machine being constructed by H. Boeken & Co., Düren, Germany. In the method of Frémy and Urbain the ramie stalks are softened by treatment with a boiling dilute caustic soda solution, after which they are heated for four hours in iron cylinders under pressure with a solution of soda ash and caustic soda, then washed and soured several times. Other similar processes have also been described using sodium silicate, phosphate or borate in order to give the fiber a finer appearance (Girard); also treatment with salts of manganic acid have been suggested;[2] also boiling with a borax emulsion of linseed oil, mineral oil, and turpentine (MacIvor and Chester). Other methods have tried the use of an alkali boil, washing, souring, then treatment with oxidising agents such as potassium permanganate, chlorine, hydrogen peroxide.[3] Also the artificial retting process of Bauer[4] has been used for ramie, and also the cold bleaching process of Pick and Erban.[5] In the process of Harris[6] the ramie stalks are impregnated with a 1 percent solution of caustic soda, steamed for six hours, washed to remove the dissolved gums, then impregnated with a 2 percent solution of common salt, or a solution of soap, caustic soda and linseed oil, and steamed again under pressure, washed and then treated with the simultaneous or alternate action of ozone and steam in a closed vessel. This is said to accomplish a bleaching and purification of the fiber in a few hours. For the cleaning of the fiber from the decomposed tissues mechanical treatments such as passing through fluted rolls (breaking), combing, etc., are required. Blachon and Peret-

[1] *Die Rohstoffe der Textilindustrie*, p. 67.
[2] *Société de la ramie.*
[3] Boyle, Bilderbeck, Comess, etc.
[4] *Ger. Pats.* 68,807 and 80,023.
[5] *Brit. Pat.* 3259 of 1904.
[6] *Ger. Pat.* 193,499; see *Jahresbericht*, 1907, p. 407.

mére [1] use hypochlorite of soda solutions for isolating the ramie fiber; Fuchs [2] uses sulfite liquors at 100° to 110° C.; and Pellmann [3] treats the ramie with baths of caustic soda containing soap and alcohol.

Many of the processes which have been suggested for the retting of flax, jute, and hemp have also been used in connection with ramie. In the process of Blackmore,[4] for instance, the raw fiber is heated with a 10 percent solution of sodium aluminate at about 95° C. in a special form of kier, which is then closed and evacuated to better remove the lye. After the addition of fresh sodium aluminate the material is heated to 4 atmospheres. Washing with warm water follows and then a treatment with carbonic acid at 7 atmospheres pressure, which opens up the fiber After thorough washing and a subsequent treatment with boiling caustic soda and washing the decortication is completed.[5]

Much has been written in the technical press concerning the vast possibilities of ramie as a textile fiber. According to Roux, however, the cost of its production will always prevent its common use for the textiles that can be more cheaply grown and prepared. While it has brilliancy it has not the elasticity of wool and silk, nor the flexibility of cotton; but it will always be preferred for making articles requiring the strength to resist the wear and tear of washing and exposure to weather. The facility with which it may be made to imitate other textiles, according to Dodge, is one of the principal causes which has kept back the development of the ramie industry. The folly of building up the industry on a basis of imitating something else is to be deprecated; the fiber should be used in those articles of common necessity which would appear on the market as ramie, so that any distinctive merit the textile may possess may become known, not only to the ramie trade, but to the consumers of the product.[6]

According to Nodin and Brettoneau, the average composition of ramie stalks, after degumming and drying, is as follows:

[1] *Ger. Pat.* 207,362.

[2] *Monatsch. Textil.*, 1909, p. 337.

[3] *Ger. Pat.* 204,334.

[4] *U. S. Pat.* 786,721.

[5] See *Faerber-Zeit.*, 1905, p. 191.

[6] Ramie yarns are successfully spun on a large scale at Baumgarten's mill (Erste Deutsche Ramie Gesellschaft) at Emmendingen, Germany. This factory is subsidised by the German Government and has the advantage of cheap labor. A considerable quantity of ramie yarn from this mill is sent to the United States, where it is chiefly used for the making of incandescent gas mantles. In the United States there are two mills producing ramie yarn with more or less apparent success (1913); these are the Springdale Fiber Co. at Canton, Mass., and the Superior Thread and Yarn Co. at Pluckamin, N. J.

	Percent.
Fiber	30
Wood	55
Bark, etc	15

The following is an analysis of ramie ribbons:

	Percent.
Ash	1.75
Nitrogen	1.28

The ash from the above contained the following constituents:

	Percent.
Potash	32.57
Soda	8.01
Lime	22.66
Magnesia	11.33
Phosphoric acid	12.57
Sulfuric acid	3.96
Chlorine	2.98
Silica	6.27

On French authority it is stated that the yield of decorticated fiber from the green, unstripped stalks amounts to about 2 percent, and of degummed fiber about 1 percent. Based on the weight of dry, stripped stalks, the yield of the degummed fiber would be about 10 percent.

The bast of the ramie cannot be removed from the woody tissue in which it is imbedded by a simple retting, as in the case of flax and other bast fibers. It must undergo a severe mechanical treatment, whereby the outer bark is removed. The long, fibrous tissue so obtained consists of the ramie filaments held together in the form of a ribbon by a large quantity of gum, and before the fibers can be combed out this gum must be removed by chemical treatment. The gummy matters seem to consist essentially of pectose, cutose, and vasculose. In the degumming, the object is to remove these substances without affecting the cellulose of the fiber proper. The vasculose and cutose may be dissolved by treatment with soap or caustic alkalies employed under pressure. The adhering pectose can then be detached mechanically by washing.

The chief difficulty in preparing decorticated ramie for spinning is the elimination of the gum which holds the fibers together. Many researches have been conducted with a view of discovering a suitable and efficient process of degumming. Previous to 1914 a considerable degree of success had been attained at Emmendingen in Germany, where large quantities of ramie yarn were produced. A bacterial system of degumming ramie has been announced by Prof. Rossi of Naples, the results of which are

said to be very satisfactory. When the fiber is properly degummed there is no particular trouble in the spinning of ramie.[1]

13. Uses of Ramie Fiber.—Though ramie has many excellent qualities to recommend it as a textile fiber for definite uses, nevertheless it lacks the elasticity of wool and silk and the flexibility of cotton.[2] As a result it yields a harsher fabric, which has not the softness of cotton. Owing to its smooth and regular surface, it is difficult to spin to fine counts, as the fibers lack cohesion and will not adhere well to each other. The ramie fiber also resists the action of chemicals perhaps better than any other vegetable fiber; it has a high luster, being more glossy than jute; it is also firmer in quality than hemp. The specific gravity of ramie yarn is less than that of linen in about the ratio of 6 to 10; on the other hand ramie yarn is denser than cotton in the ratio of about 6 to 5.

One of the principal uses of the ramie fiber at present is for the making of yarns used in the manufacture of gas-mantle fabric, for which it is the most suitable material yet found, giving stronger and more resilient mantles than any other material.[3] Its chief competitor in this respect is artificial silk. Ramie is also used to some extent for making fishing nets and for knit underwear. As its absorbent properties are excellent, it should be suitable for the manufacture of surgical bandages and hospital gauze. It has been suggested as a substitute for linen, but as cloth made from ramie tends to crack when folded it would not be a suitable substitute in linen collars and cuffs, and it is also doubtful if it would wear well in tablecloths, sheets and similar articles.

Ramie in the form of combed silver glued into a coherent web is also extensively employed as material for hat braids and trimmings. To be made into this form the ramie fiber is well combed so as to parallel the fibers in a thin and uniform web. This web is wound on a suitable roller, and then run through a machine provided with an endless apron (made of polished white metal or copper), so that a solution of gelatine (100 parts of gelatine and 275 parts of water) is applied to both sides of the web.

[1] According to the process used by the Ramie-Spinnerei Emmendingen (*Ger. Pat.* 115,745) the ferment material is made from ramie waste; the ferment is allowed to act for several days, after which the material is boiled for three hours at 2 atmospheres pressure with dilute caustic soda solution, washed, squeezed and dried, and then further purified by mechanical means to make the fiber ready for spinning. It is said that the cost of the process amounts to less than $\frac{1}{4}$ cent per pound of ramie fiber. The process, however, gives rise to such a stench and creates such a nuisance that it would hardly be tolerated in American practice.

[2] The price for raw decorticated ramie in England for 1920 was £120 to £150 per ton, as compared with prices in 1914 of £40 to £80.

[3] For this latter purpose it appears to be especially adapted, as it readily absorbs the solutions of metallic salts (cerium and thorium) employed for this purpose, and after ignition it leaves an ash skeleton or mantle possessing considerable strength and resiliency.

After passing through squeeze rolls the web is carried through a drying chamber.[1] To prevent the gummed web from sticking to the metal apron, the latter is coated by means of a spray with a solution of 8 parts of white wax in 100 parts of turpentine. The gummed web is next cut into strips of the desired width. In order to waterproof the web and then prevent the strips from disintegrating when dyed, the strips are hung in a closed chamber and treated with the vapor of formic acid. Treatment

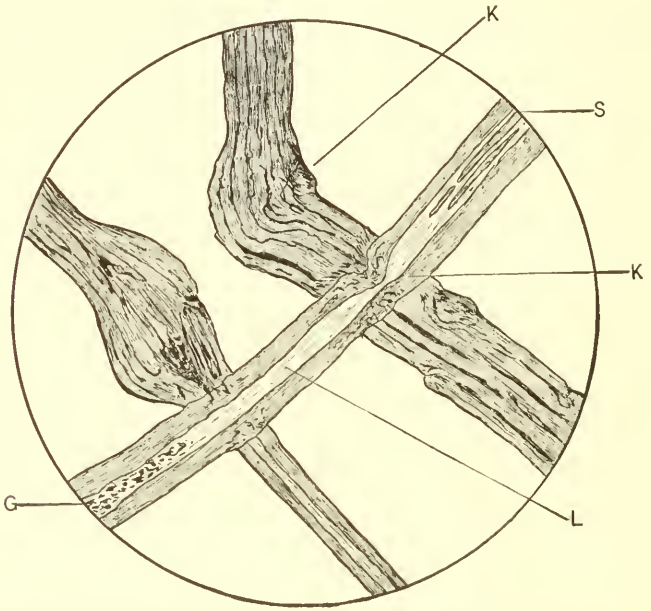


FIG. 312.—Ramie Fiber. (×350.) *L*, Lumen; *G*, granular matter in lumen; *S*, long shreds of matter in lumen; *K*, knots in fiber. (Micrograph by author.)

with solutions of chrome or tannin might also be employed for the same purpose.

In order to make the gelatine solution more transparent, from 5 to 10 percent of alcohol may be added. Collodion, gums, varnishes, and other substances may also be employed to produce different effects.

14. Microscopy of Ramie.—Microscopically the ramie fiber is remarkable for the large size of its bast-cells. These are from 60 to 250 mm. in length and up to 80 microns in width. The diameter of the fiber is also characteristically uneven, sometimes narrow with heavy cell-walls and well-defined lumen and at other times broad and flat with an indistinct

[1] For description of a machine for applying the gelatine solution, see *Textile World Record*, 1913, p. 594.

lumen, but showing heavy striations along the fiber.[1] The ratio of the length of the fiber to its breadth is about 1 : 2400. The fiber consists of pure cellulose with no indication of the presence of any lignin as iodine and sulfuric acid give a pure blue stain, and aniline sulfate gives no color. In an ammoniacal solution of copper oxide ramie becomes greatly swollen, but does not dissolve. The ramie fiber gives a blue coloration with the chlor-iodide of zinc reagent, and rose-red with chlor-iodide of calcium; *white ramie* gives no coloration with aniline sulfate, but *green ramie* gives a slight yellow color, which seems to indicate a slight degree of lignification in the case of the latter fiber. Along the fiber, joints and transverse fissures are of frequent occurrence (Fig. 312). The lumen is especially broad and easily noticeable. The ends of the fiber elements have a thick-walled, rounded point, and the lumen is reduced to a line. At places the lumen

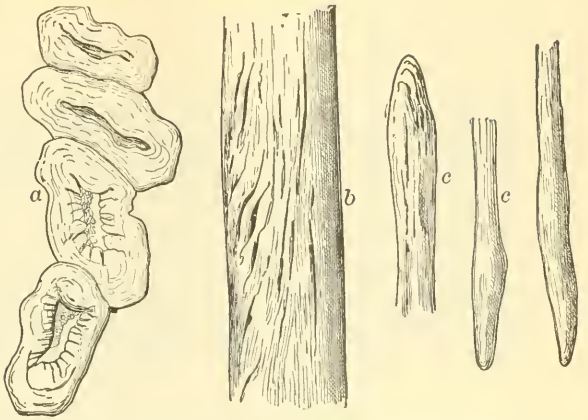


FIG. 313.—Ramie Fiber. *a*, Sections; *b*, longitudinal view; *c*, ends. (Cross and Bevan.)

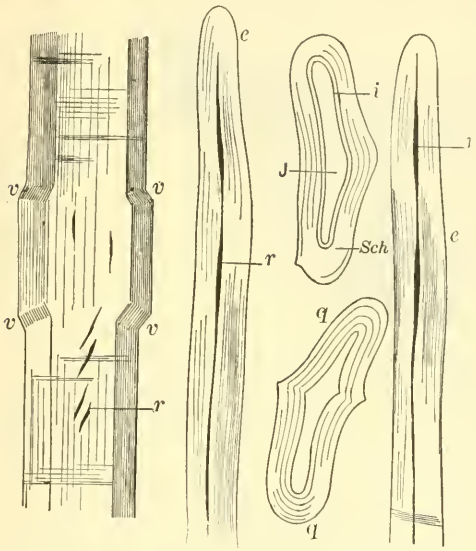


FIG. 314.—Ramie Fiber. *v*, Swollen displacements; *r*, fissures; *e*, point or end; *q*, cross-sections; *i*, inner layers of fiber-wall; *J*, lumen; *sch*, stratifications. (Höhnel.)

[1] In this connection Hassack gives the following figures:

	Fiber Diameter in Mm.
Ramie	9.04 to 0.06
Linen	0.016
Cotton	0.014 to 0.024
Silk	0.009 to 0.024

Ramie is also distinguished by the great length of its fiber, the individual fibers

appears to be more or less filled with granular matter, and sometimes with long uneven shreds of matter, evidently dried-up albuminous matter. The cross-section of the fiber (Fig. 313) shows usually only a single element or a group of but a few members. The cross-section is also quite large, and is elliptical in shape; the lumen appears open, and frequently contains granular matter. The cross-section also frequently shows strong evidence of stratification (Fig. 314). The fibers are frequently very broad, and at these parts are flat and ribbonlike in form, but are never twisted.

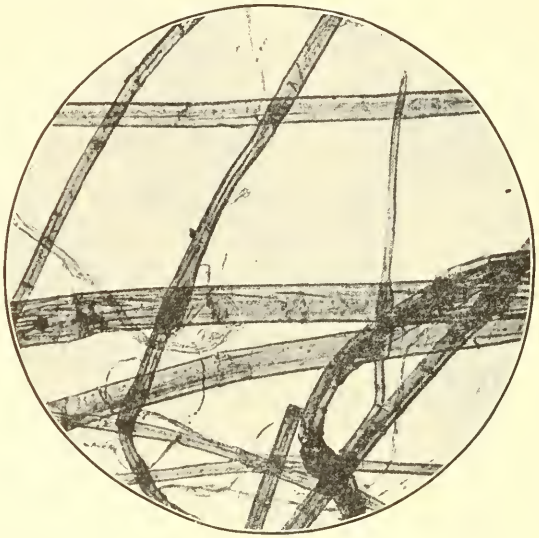


Fig. 315.—Ramie Fibers Stained with Iodine and Sulfuric Acid. (Herzog.)

Müller gives the following analysis of the raw fiber of samples of both China grass and ramie:

Constituent.	China Grass, Percent.	Ramie, Percent.
Ash	2.87	5.63
Water (hygroscopic)	9.05	10.15
Aqueous extract	6.47	10.34
Fat and wax	0.21	0.59
Cellulose	78.07	66.22
Intercellular substances and pectin	6.10	12.70

being usually from 4 to 6 ins. in length, though they may at times reach as much as 10 to 16 ins. This is rather unusual in the case of bast fibers which are generally made up of rather short fiber elements.

15. Commercial Aspect of Ramie.—The amount of ramie fiber coming into either England or America is still quite insignificant as compared with

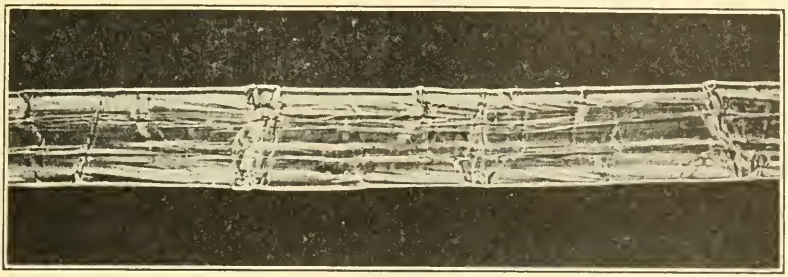


FIG. 316.—Ramie Fiber under Polarised Light. (Herzog.)

the other chief textile fibers.[1] It is said that recently ramie is being used quite extensively in the Irish linen mills to blend with flax in spinning

[1] The following table shows the amount of ramie fiber exported from China during recent years, as shown by the customs returns:

Countries of Destination.	1917. (Tons.)	1918. (Tons.)	1919. (Tons.)	1920. (Tons.)
France	432	734	135	179
Great Britain	1,265	1,445	295	1,309
Hongkong	386	642	317	319
Japan	14,958	13,658	13,096	10,303
United States (including Hawaii and the Philippine Islands)	1,337	1,784	25	2
All others	84	45	194	356
Total	18,462	18,308	14,062	12,468

Exports of ramie or grass cloth from China in 1917 were valued at about $2,000,000; in 1918, at $2,500,000; and in 1919, at $5,000,000. The following table shows the quantity and destination of exports:

Countries of Destination.	1917. (Tons.)	1918. (Tons.)	1919. (Tons.)	1920. (Tons.)
Hongkong	101	82	82	113
Japan	68	100	135	131
Korea	820	707	1472	1388
Philippine Islands	2	1	3	2
Straits Settlements	61	61	57	82
All others	....	....	....	10
Total	1052	951	1751	1726

Kiukiang and Swatow are the original points of export of two-thirds of the entire amount of grass cloth exported from China, Chungking and Shanghai making a distant third and fourth. Two-thirds of the grass cloth exported from all China is sent to Hankow, Chinkiang and Shanghai, where it supplies the re-export trade and the demand for local consumption.

and that the resultant fabrics are of the most desirable quality, being equal to the best Irish linen goods. It is also claimed that Italian hemp is being used in the same connection.

There is no doubt that ramie could be successfully spun into yarns of very satisfactory fineness and quality if a sufficient cheap supply of the decorticated and degummed " filasse." could be obtained. The objections heretofore raised in most quarters to the spinning of ramie fiber have been based on the fact that the machinery employed was not especially designed for the treatment of this fiber, but was machinery really intended for other purposes—for preparing and spinning cotton, wool, or linen. If the working qualities of this fiber were properly studied and suitable machinery were designed for handling it specifically, there would be no particular difficulties in the preparation of fine ramie yarns.

Fig. 317.—Ramie Fiber. (×420.) Showing the longitudinal ridges and knot-like cross-markings. (Micrograph by author.)

One fault to be met with in some qualities of ramie is that known as " hard ends," being generally fibers that have not developed to their full length, but have grown thick and short, or two or three fibers that have grown together. In a satisfactory combing process these hard ends will be almost wholly removed from the slivers, but if they are not completely gotten rid of the yarn will exhibit inequalities and the resultant cloth will have a speckled appearance after dyeing.

It has also been suggested to cut ramie fiber into relatively short lengths similar to cotton, then wind it with the latter fiber and spin it into yarns. But just what advantage would be gained by this is difficult to understand, as it would be impairing the qualities of a long strong fiber to make it complete with cotton, a much cheaper material.

16. Hemp.—This is a name applied to a large number of bast fibers more or less analogous in appearance and properties. Among the different varieties of hemp appearing in trade may be enumerated the following (Dodge):

Ambari (or brown) hemp ..... *Hibiscus cannabinus*
Bengal (or Bombay) hemp ..... *Crotalaria juncea*

Black-fellow's hemp	*Commersonia fraseri*
Bowstring hemp (Africa)	*Sanscvieria guineensis*
Bowstring hemp (Florida)	*S. longiflora*
Bowstring hemp (India)	*S. roxburghiana*
Calcutta hemp	Jute
Cebu hemp	*Musa textilis*
Colorado River hemp	*Sesbania macrocarpa*
Cretan hemp	*Datisca cannabina*
Cuban hemp	*Fourcroya cubensis*
False hemp (American)	*Rhus typhina*
False sisal hemp	*Agave decipiens*
Giant hemp (China)	*Cannabis gigantea*
Hayti hemp	*Agave fœtida*
Ifé hemp	*Sansevieria cylindrica*
Indian hemp	*Apocynum cannabinum*
Jubbulpore hemp (Madras)	*Crotalaria tenuifolia*
Manila hemp	*Musa textilis*
New Zealand hemp (or flax)	*Phormium tenax*
Pangane hemp	*Sansevieria kirkii*
Pita hemp	*Yucca* sp.
Pua hemp (India)	*Maoutia puya*
Queensland hemp	*Sida retusa*
Rangoon hemp	*Laportea gigas*
Roselle hemp	*Hibiscus sabdariffa*
Sisal hemp	*Agave rigida*
Sunn hemp	*Crotalaria juncea*
Swedish hemp	*Urtica dioca*
Tampico hemp	*Agave heteracantha*
Water hemp	*Eupatorium cannabinum*
Wild hemp	*Maoutia puya*

Hemp proper, or the so-called *common hemp,* is derived from the bast of *Cannabis sativa.* This is a shrub [1] growing from 6 to 15 ft. in height, and though originally a native of India and Persia, it is now cultivated in nearly all the temperate and tropical countries of the world. At the present time it is quite extensively grown in America,[2] though not as yet

[1] The hemp is an annual plant, with a straight stalk, and elongated, highly dentated leaves. The latter have a narcotic odor, and occur in bunches of three, five, or seven. The flower is without petals and develops into the well-known hemp-seed on maturity. The hemp plant is dicœcious; that is, it belongs to the class of plants in which the sexes are divided, some stems bearing only clusters of male flowers (panicles), while others bear only female flowers (catkins). The female plant grows from 6 to 8 ft. in height, while the male plant (*fimble hemp*) is shorter.

[2] Several varieites of hemp are grown in this country, that cultivated in Kentucky and having a hollow stem being most common. China hemp and Smyrna hemp are also grown, and in California, Japanese hemp is cultivated and gives a remarkably fine product. Five varieties of hemp appear to be cultivated in Europe: the common hemp, Bologne hemp (known also as Piedmontese hemp or great hemp), Chinese hemp, small hemp (the *Canapa piccola* of Italy), and Arabian hemp. The latter is also known as Takrousi and is chiefly cultivated for its resinous principle, from which hasheesh is obtained.

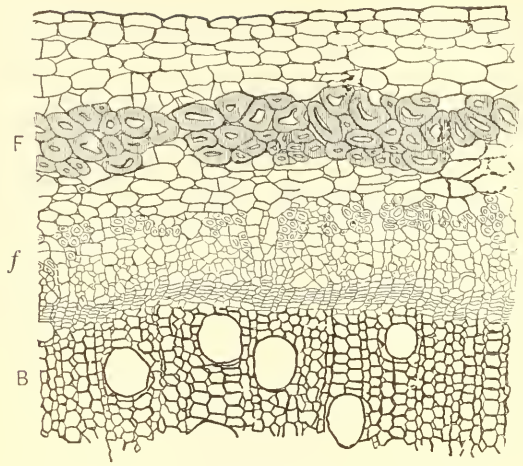


Fig. 318.—Part of Cross-section of Hemp Stalk. *B*, Woody tissue; *f*, secondary layer of fibers; *F*, main layer of fibers. (Le Comte.)

obtained.[1] Japanese hemp is of excellent quality, and appears in trade in the form of very thin ribbons, smooth and glossy, of a light straw color, and the frayed ends showing a fiber of exceeding fineness. Hemp appears to have been the oldest textile fiber used in Japan.

Italian hemp has been suggested as a possible substitute for linen in the preparation of fabrics. It has not as yet, however, been spun to a very fine thread, though in Belgium it has been successfully in sufficient amount to satisfy the home consumption. Russia produced an enormous quantity of hemp; in fact, this fiber formed a staple article of export from that country. Poland is also a large producer. French hemp, though not grown to such an extent, is much superior in quality to that from either Russia or Poland, it being fine, white, and lustrous. Italian hemp is also of a very high grade. In India hemp is not grown so much for its fiber as for the narcotic products

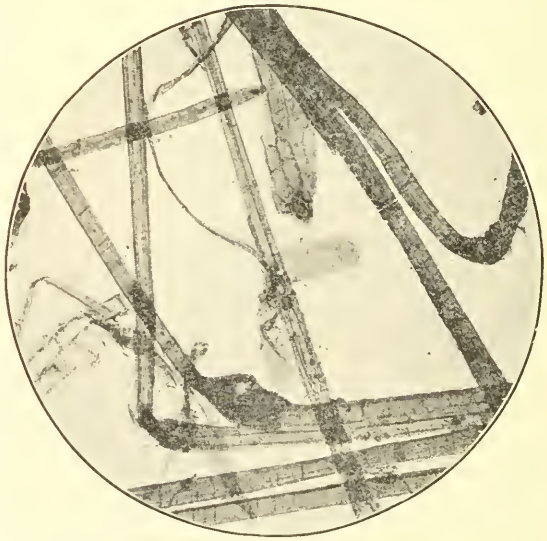


Fig. 319.—Hemp Fiber from *Cannabis sativa*. (Herzog.)

[1] Hemp grows wild throughout Indian but it is regarded as the source of the drug known as bhang or hasheesh, rather than as a fiber plant. Dodge states that the use of hemp among the ancients was very limited; it is not mentioned in the Scriptures and is rarely referred to by the writers of antiquity. It was apparently used by the Scythians at least as early as 500 B.C., and some writers attribute to its cultivation an antiquity more remote by 1000 years. The Romans were familiar with the use of hemp for the making of sails and cordage, though not until after the Christian era.

spun up to 35 lea on a commercial scale. Italian hemp is at present used mostly for twine, though there is evidently possibility for its use in the making of finer yarns. The chief difficulty in the spinning of hemp is that it must be properly softened before it can be used, and it can be a satisfactory substitute for linen only when the softening process has been most thoroughly carried out. Also, on account of its lack of elasticity Italian hemp yarn tends to break when used as a warp, even when blended with flax.

17. Preparation of Hemp.—The hemp fiber is obtained from the plant by a process of retting similar to that employed for flax [1] the plant being passed through about the same operations, such as rippling, retting, breaking and heckling. The broken hemp is known as *bast hemp*, and the heckled as *pure hemp*. The latter is separated into shoemaker's and spinning hemp. The tow separated in hackling is used for stuffing in upholstery. The method of dew-retting is chiefly used; that is, the stalks are spread out in the fields until the action of the elements causes the woody tissue and gums enclosing the fibers to decompose. Retting in pools of water has been practised to a slight extent, but evidently not with much success.[2] It is said that 100 parts of raw hemp furnish 25 parts of raw fiber or filasse; and 100 parts of the latter yield 65 parts of combed filasse and 32 parts of tow.

Hemp fiber, prepared by water-retting as practised in Italy,[3] is of a creamy-white color, lustrous, soft, and pliable. It makes a satisfactory substitute for flax, and is used for medium grades of nearly all classes of goods commonly made from flax, except the finer linens. When prepared by dew-retting, as practised in this country, the fiber is gray, and somewhat harsh to the touch. It is used for yacht cordage, ropes, fishing-lines, linen crash, homespuns, hemp carpets, and as warp in making all kinds of carpets and rugs.

The commercial fiber is pearly gray, yellowish or greenish to brown in color, and from 40 to 80 ins. in length. Its fineness of staple is less than that of linen, though its tensile strength is appreciably greater. The best qualities of hemp are very light in color and possess a high luster almost equal to that of linen. The annual production of hemp fiber is about 600,000,000 lbs.

Spanish hemp, of which there is a very large crop, is irregular and unreliable; it is practically the same fiber as Italian hemp, but it is of

[1] The plant is ready for pulling when the lower leaves become limp and the tip of the stalk turns yellowish. The male plants are pulled first and the female plants about 2 to 3 weeks later.

[2] *Baden hemp*, which is a much-prized variety, is prepared by stripping the bast from the retted stalks by hand. The product is entirely free from shives.

[3] The total crop of hemp fiber in Italy for 1920 amounted to about 100,000 tons.

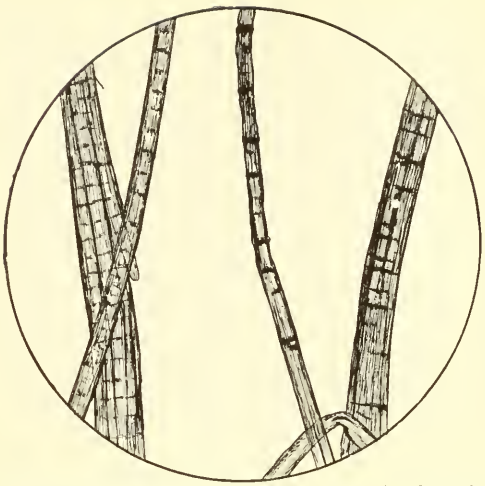


Fig. 320.—Fibers of Hemp. (×300.) Showing longitudinal fissures and transverse cracks and jointed-like structure. (Micrograph by author.)

inferior quality. Hungarian hemp is of better quality and some ranks equal to the Italian fiber; Russian hemp is also of the same general character.

The seed of the hemp plant, like that from flax, is also utilised for the oil it contains;[1] 100 parts of seed furnish 27 parts of oil. So this forms an extensive and important by-product in the cultivation of hemp.

18. Microscopy of Hemp.—Under the microscope the hemp fiber is seen to consist of cell elements which are unusually long, averaging about

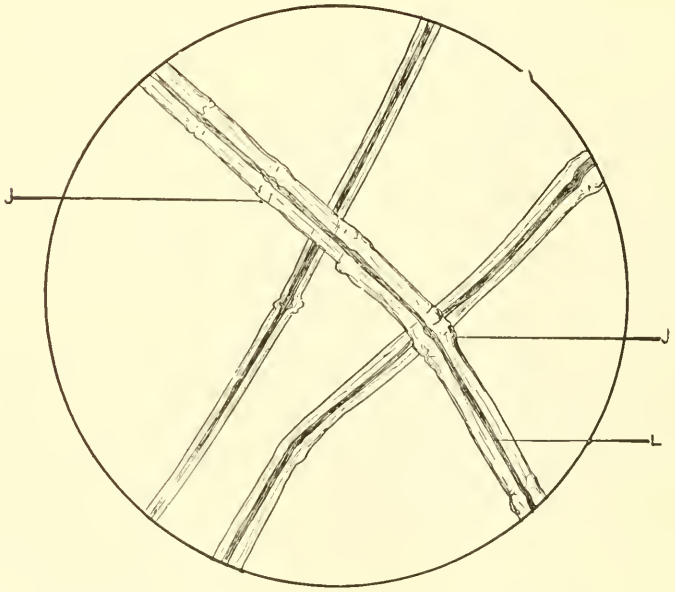


Fig. 321.—Hemp Fibers. (×300.) *L*, Lumen; *J*, joint-like structure. (Micrograph by author.)

[1] Hemp seed yields a greenish colored oil having a peculiar odor. It is used in the making of green soap for the preparation of artist's colors and varnishes, and in some localities for the making of oil-gas. Hemp seed is also used as a bird food, and in some countries (Russia) is an article of diet.

20 mm. in length, but varying from 5 to 55 mm. The diameter, however, is very small, averaging 22 microns and varying from 16 to 50 microns. Hence the ratio between the length and diameter is about 1000. The fiber is rather uneven in its diameter, and has occasional attachments of fragmentary parenchymous tissue. In its linear structure the fiber exhibits frequent joints, longitudinal fractures, and swollen fissures (Fig. 320). The lumen is usually broad, but toward the end of the fiber it becomes like a line (Fig. 321). It shows scarcely any contents. The ends of the filaments are blunt and very thick-walled, and often possess lateral branches.[1] The cross-section generally shows a group of cells which nearly always have rounded edges and are not so sharp-angled and polygonal as in the case of jute (Fig. 322). There is also a median layer between the cells, which is evidenced by it

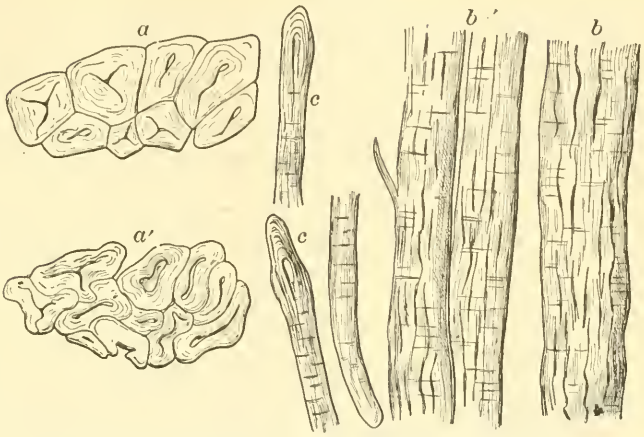


FIG. 322.—Hemp Fibers. *b*, Longitudinal views; *c*, ends; *a*, cross-sections. (Cross and Bevan.)

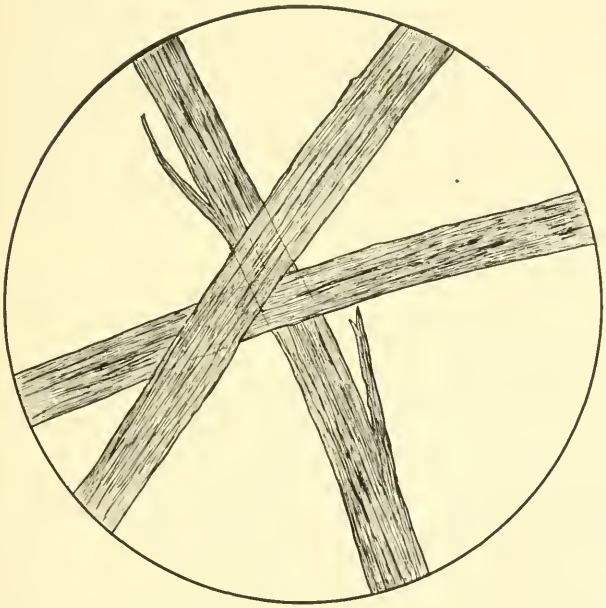


FIG. 323.—Hemp Fibers. (×300.) (Micrograph by author.)

[1] Forked ends are very characteristic of hemp fibers, but such a condition is never observed with flax.

turning yellow on treatment with iodine and sulfuric acid. In the section the lumen appears irregular and flattened, and does not show any contents. The cell-walls frequently exhibit a remarkable stratification, the different layers yielding a variety of colors on treatment with iodine and sulfuric acid.

The intercellular (median layer) matter which binds the elements of the hemp together contains vasculose, and even the cellulose of the fiber itself appears to be impregnated with this substance. This is the cause of the stratified appearance of the cell-wall when the fiber is treated with the iodine-sulfuric acid reagent. When the hemp fiber is viewed longitudinally and is treated with the above reagent, a green color is obtained, due to the mixing of the yellow of the vasculose layer and the blue of the cellulose layer. By this means hemp may readily be distinguished from linen, which gives a characteristic blue color.

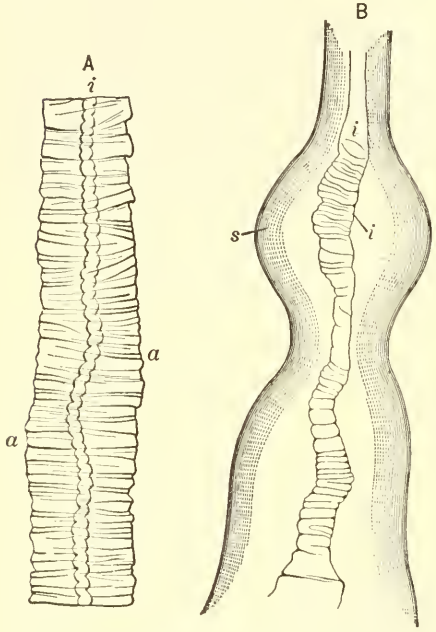


FIG. 324.—Hemp Fibers Treated with Schweitzer's Reagent. *A*, Strongly lignified fiber; *B*, fiber free from ligneous matter; *i*, *i*, skin of inner canal; *a*, external ligneous tissue; *s*, swollen cellulose. (Wiesner.)

When examined under polarised light, hemp shows very bright colors similar to linen and ramie. Hemp also gives the following microchemical reactions: (*a*) with iodine-sulfuric acid reagent, bluish green coloration; (*b*) with chlor-iodide of zinc, blue or violet, with traces of yellow; (*c*) chlor-iodide of calcium, rose red with traces of yellow; (*d*) aniline sulfate, yellowish green coloration; (*e*) ammoniacal fuchsine solution, pale-red coloration; (*f*) with Schweitzer's reagent the hemp fibers swell irregularly with a characteristic appearance (Fig. 324) and after a while dissolve almost completely, leaving only the fragments of parenchymous tissue.

Hemp is sometimes difficult to distinguish microscopically from flax; but the two may readily be told by an examination of the ends of the fibers, hemp nearly always exhibiting specimens of forked ends, whereas flax never has this peculiarity. The fibers of hemp are also less transparent than those of linen, and the interior canal is often more difficult to distinguish, on account of the numerous striations on the surface. The difference

in the appearance of the cross-sections is also of service in discriminating between these two fibers. Again, the parenchymous tissue which frequently occurs as attached fragments to hemp fibers is rich in star-shaped crystals of calcium oxalate, and this is scarcely ever to be noticed in the case of flax. A peculiarity to be noticed in the examination of hemp is the occasional presence of long narrow cells filled with reddish brown matter, insoluble in the ordinary solvents. These cells occur between the fibers as well as in the bast, and probably contain tannin. They are not to be found in flax. The behavior of isolated hemp cells with ammoniacal copper oxide solution is also quite characteristic; the cell membrane acquires a blue to a bluish green color, and swells up like a blister, showing sharply defined longitudinal striations. The inner cell-wall

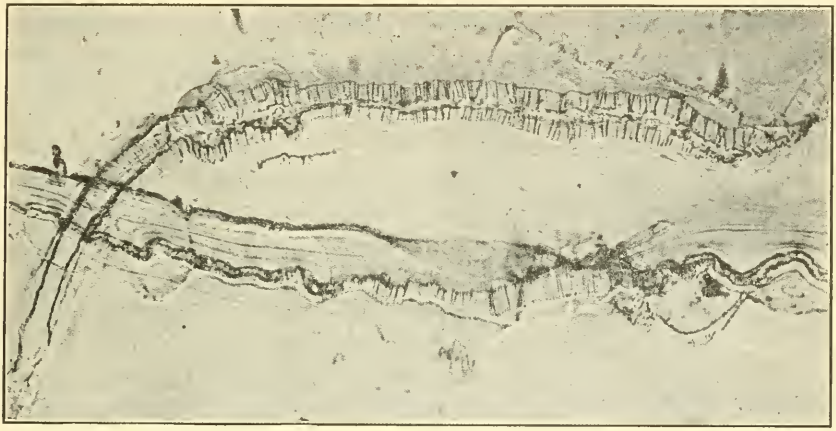


FIG. 325.—Hemp Fibers Treated with Schweitzer's Reagent. (Herzog.)

remains intact in the form of a spirally wound tube contained inside the strongly swollen mass of the fiber.

The hemp fiber is not composed entirely of pure cellulose, as it gives a yellow to yellowish green coloration with aniline sulfate, and a greenish color with iodine and sulfuric acid. Both hydrochloric acid and caustic potash give a brown coloration, while ammonia produces a faint violet. It appears to be a mixture of cellulose and bastose. Bleached hemp, however, shows the reactions of pure cellulose. Müller gives the following analysis of a sample of the best Italian hemp:

	Percent.
Ash	0.82
Water (hygroscopic)	8.88
Aqueous extract	3.48
Fat and wax	0.56
Cellulose	77.77
Intercellular matter and pectin bodies	9.31

It is claimed [1] that hemp may be mercerised by soaking the fiber for several hours in a vat containing caustic soda solution of 10° to 30° Bé. then hydroextracting, washing in dilute soap solution, acidifying with hydrochloric or acetic acid and washing again. The hemp is said to acquire a softer feel, and becomes curly, clear, and silky in appearance.

19. Properties and Uses of Hemp.—Hemp appears to contain more hygroscopic moisture than cotton or linen. Samples examined by the author contained 8 percent moisture compared with 6 percent for cotton under the same conditions. At the Roubaix conditioning house the regain allowed on hemp is 12 percent, and this same figure was fixed by the International Congress at Turin.

Hemp is principally employed for the manufacture of twine and cordage, for which its great strength eminently adapts it; and, besides, it is a very durable fiber, and is not rotted by water. In this respect it differs very essentially from jute. Ordinary hemp is seldom used, however, for woven textiles, as it is harsh and stiff, and not sufficiently pliable and elastic. It also possesses a rather dark-brown color, and cannot be successfully bleached without serious injury to the quality of the fiber.

20. Cuban Hemp.—Cuban hemp of trade is the fiber from *Fourcroya cubensis*, a plant native to tropical America, and having long leaves in which the fiber is found. The fiber is of very good quality and is similar to sisal hemp. Another species, the *F. gigantea*, or giant lily, also gives a good fiber which closely resembles sisal hemp and no doubt is often sold in trade for this latter fiber. It is also grown in tropical America, and the fiber is called by the natives *fique*, and is principally employed for the making of bagging, horse blankets, etc. It is known in Venezuela as *cocuiza*.

21. Sunn Hemp is the bast fiber of the *Crotalaria juncea;* it is also known by the names of Conkanee, Indian, Brown, and Madras hemp. It grows abundantly in the countries of southern Asia, and is largely used in the manufacture of cordage. It appears to have been one of the earliest fibers mentioned in Sanscrit literature. It was known in the Institutes of Manu under the name of *sana*.[2] This hemp was also probably known to the Chinese at a very remote date. The fiber is obtained from the plant by a system of retting very similar to that of flax.

True Indian hemp is the bast fiber from *Apocynum cannabinum;* this fiber is a light cinnamon in color and is long and tenacious. It was principally employed by the North American Indians, who made bags, mats, belts, and cordage from it. Spon mentions Indian hemp under the com-

[1] *Fr. Pat.* 510,525.

[2] The term *sana* is supposed by some authorities to refer to sunn hemp, though Dr. Watt seems to be of the opinion that the term designated a group of fibers, sunn, sanpat, or *Hibiscus cannabinus*, and common hemp, *Cannabis sativa*. Dodge, however, thinks that the evidence is in favor of sunn hemp alone.

mon name of "Colorado hemp," but this latter name really belongs to the fiber from *Sesbania macrocarpa*. To the same family (*Papilionaceæ*) as sunn hemp belong two other species of plants which yield valuable fibers for paper manufacture—namely, Spanish broom (*spartium junceum*) and German broom (*Spartium scoparium*).

Another fiber of India resembling sunn hemp is known as *Devil's cotton* (*Abroma augusta*). The plant yields three crops a year and is more easily cultivated than jute or sunn hemp. The fiber is from the bast of the twigs, and is strong, white, and clean, and much valued for local uses. Watt states that it might be employed as a substitute for silk, therefore it is probable that the fiber has a high degree of luster. According to Royle, a cord of this fiber bore 74 lbs. against a similar cord of sunn hemp that broke with 68 lbs. It is chiefly employed locally as a cordage fiber. The fiber of sunn hemp is of a better quality than jute, being lighter in color, of a better tensile strength, and more durable to exposure.

FIG. 326.—Leaf and Blossom of Sunn Hemp (*Crotalaria juncea*). (After *Bulletin* U. S. Dept Agric.)

The following tables of comparative tensile strengths for various cordage fibers have been adopted from Royle's work on *The Fibrous Plants of India;* the tests were made on ropes of the same size and 1.2 meters in length.

I. COMPARATIVE STRENGTH, DRY AND WET

Fiber.	Dry, Kilos.	Wet, Kilos.
Hemp from Calcutta	72	86
Sunn hemp (fresh retted)	51	72
" (retted after drying)	27	35
Jute (*Corchorus capsularis*)	65	66
" (*C. olitorius*)	51	56
" (*C. strictus*)	47	52
Gambo hemp (*Hibiscus cannabinus*)	52	60
Roselle hemp (*H. sabdariffa*)	41	53
Hibiscus abelmoschus	49	49
Ramie (*Bœhmeria tenacissima*)	110	126

II. Comparative Strength of Prepared Ropes, and after Steeping in Water 116 Days

Fiber.	Prepared Ropes.			Water-soaked. Natural.
	Natural.	Tanned.	Tarred.	
Hemp, English	47	....	....	Rotted
" Calcutta	34	63	20	"
Coir	39	....	....	24
Sunn hemp	31	31	27	Rotted
Jute	31	31	28	18
Linen, Calcutta	17	....	....	Rotted
Agave americana	50	36	35	"
Sansevieria zeylanica	54	33	22	13

Dr. Wright gives the following table for the strength of several cordage fibers:

	Pounds.
Sunn hemp	407
Cotton rope	346
Hemp	290
Coir	224

According to Roxburgh, similar lines of jute and sunn hemp showed the following comparative tensile strengths:

	Dry.	Wet.
Jute	143	146
Sunn hemp	160	209

In appearance sunn hemp is very similar to hemp, both to the naked eye and under the microscope. The raw fiber is coarse, flattened, and dark gray in color; the purified fiber is yellowish gray, rather lustrous, and of a fine texture.

The essential distinction between sunn hemp and hemp is in the cross-section of the former (Fig. 327), which shows the presence of a very thick median layer of lignin between the individual cells. The lumen in the cross-section is also usually rather thick, and often contains yellowish matter differing in these respects from hemp, in which the lumen is flat and narrow and always empty. The bast-cells of sunn hemp are 13 to 50 microns broad, and in longitudinal view are partly striated, and also

show dislocations and cross-marks. The ends are thickened and either blunt or narrowed with warty irregularities. Iodine and strong sulfuric acid produce a peculiar swelling of the fiber, the outer yellow layer becoming converted into a yellow mass over which flows the blue semi-liquid mass of cellulose, leaving as a residue a greenish yellow inner tube. With iodine and sulfuric acid sunn hemp gives a greenish blue coloration, and with chlor-iodide of zinc brownish blue. This would indicate that the fiber is of rather pure cellulose, but enveloped with a layer of lignified tissue.

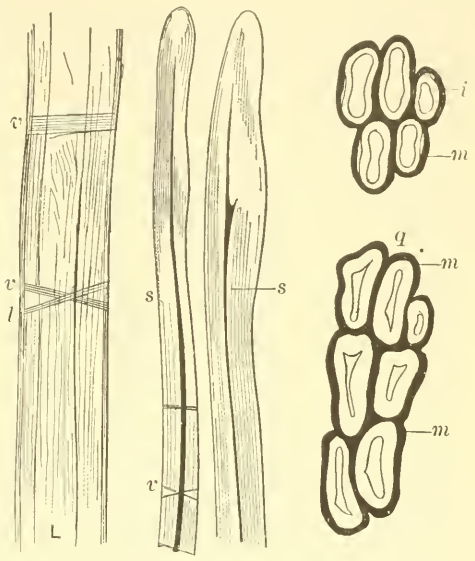


Fig. 327. Sunn Hemp. (×325.) *L*, View of middle portion; *v*, joints; *l*, lumen; *s*, pointed ends; *q*, cross-sections; *m*, outer layer of fiber; *i*, inner layers. (Höhnel.)

Another variety of *Crotalaria* used for its fiber is the *C. tenuifolia* from which is obtained the Jubbulpore hemp. This fiber is said by some to be superior to that of Russian hemp (*Cannabis sativa*), its relative tensile strength being 95 lbs. to 80 lbs. for the latter. The fiber is 4 to 5 ft. in length, and resembles the best Petrograd hemp. The fiber *C. retusa* is also to be found in India under the name of sunn hemp; *C. sericea* and *C. striata* are other species which are also employed for fiber.

Müller gives the following analysis of raw sunn hemp:

	Percent.
Ash	0.61
Water (hygroscopic)	9.60
Aqueous extract	2.82
Fat and wax	0.55
Cellulose	80.01
Pectin bodies	6.41

According to Wiesner sunn hemp contains a lower percentage of moisture than any other vegetable fiber. He gives the amount for air-dried fiber as 5.34 percent, and after exposure to an atmosphere saturated with steam as 10.87 percent. It is probable, however, that after being stored for some time the fiber of sunn hemp will show a higher percentage of moisture.

22. Ambari or **Gambo Hemp** is an East Indian fiber derived from the bast of *Hibiscus cannabinus*. The fiber when carefully prepared is from 5 to 6 ft. in length; it is of a lighter color than hemp, and harsher. Its tensile strength is somewhat less than that of sunn hemp. Like the latter fiber, it is principally used for cordage, though it is also employed in India for the manufacture of a coarse canvas. In its microscopic characteristics ambari hemp is very similar to jute; the length of the fiber elements varies from 2 to 6 mm. and the diameter from 14 to 33 microns. The median layers of lignin between the cells are broad, and are colored much darker than the inner layers of the cell-wall when treated with iodine and sulfuric acid. The lumen presents the same appearance as with jute (Fig. 328), having such very marked contractions that in places it is discontinuous. The ends of the fibers are very blunt and thick-walled. The fiber is said to be white, soft, and silky, and some claim it to be more durable than jute for the manufacture of coarse textiles. In the opinion of the author, however, these qualities of this fiber have been somewhat overestimated, as it is not as white and soft as such descriptions would lead us to expect. According to Dodge, the fibers of ambari hemp, as compared with those of ordinary hemp, are of a paler brown color, are harsher, and adhere more closely together, though the separate fibers are further divisible into fine fibrils which possess considerable strength. According to Watt, the fibers of ambari hemp are largely employed by the natives of India for the manufacture of ropes, strings, and sacks which are principally used among the agricultural districts. The length of the extracted fiber varies between 5 and 10 ft.; the fiber is somewhat stiff and brittle, and though used as a substitute for hemp and jute is inferior to both. The breaking strain has been variously estimated at 115 to 190

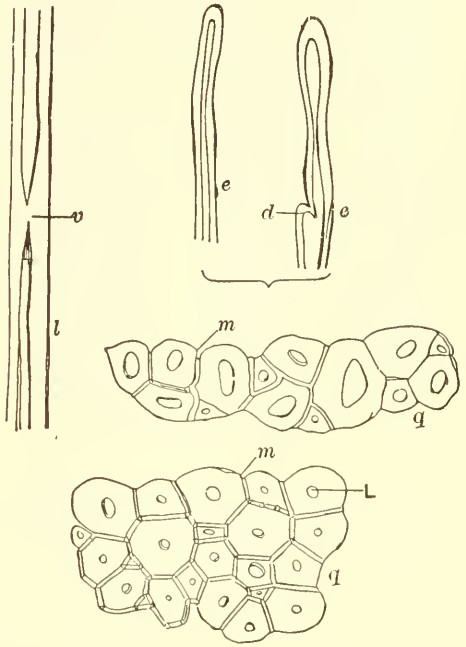


Fig. 328.—Gambo Hemp. (×325.) *e*, Ends with blunt points and wide lumen; *d*, lateral branch; *l*, longitudinal cutting with *v*, interruptions in lumen; *q*, cross-sections, with *L*, small lumen; *m*, median layers. (Höhnel.)

lbs. The fiber is bright and glossy, but coarse and harsh. Samples of the fiber exposed for two hours to steam at 2 atmospheres, followed by boiling in water for three hours, and again steamed for four hours, lost only 3.63 percent by weight as against flax 3.50; Manila hemp 6.07; hemp 6.18 to 8.44; and jute 21.39 percent.

Another variety of *Hibiscus* which is sometimes used as a fiber plant is the *H. esculentus*, or common okra. The bast of this plant at one time attracted considerable attention in the Southern States as a possible substitute for jute in the manufacture of bagging for cotton. The fiber is said to be as white as New Zealand flax, considerably lighter than jute, but more brittle and not so strong. The filaments, however, are smooth and lustrous and quite regular. It is used somewhat in India for the manufacture of twine and cordage, and as an adulterant for jute. According to the tests of Dr. Roxburgh, the fiber of Indian okra gave the following results compared with hemp and jute:

	Breaking Strain, Lbs.	
	Dry.	Wet.
Indian okra	79	95
Jute	113	125
Hemp (Bengal)	158	190
Hibiscus cannabinus	115	133
H. sabdariffa	95	117
H. strictus	104	115
H. furcatus	89	92

The bast fiber of *H. tiliaceus* (the *majagua*) has some interest in the fact that, according to the experiments of Dr. Roxburgh, it does not rot when immersed in water for a long period, as most other fibers do. His results were as follows: A cord of this fiber when white had a breaking strain of 41 lbs.; when tanned, 62 lbs.; and when tarred, 61 lbs.; a similar cord when macerated in water for 116 days, when white broke with 40 lbs.; when tanned, 55 lbs.; and when tarred, 70 lbs. English hemp and Indian hemp when treated in the same manner were found to be rotten, and sunn hemp broke with 65 lbs., and jute with 60 lbs.

23. New Zealand Flax or **Hemp** differs somewhat from the preceding fibers in that it is derived not from the bast, but from the leaves of the flax lily, *Phormium tenax*. Botanically these are known as sclerenchymous fibers. Apart, however, from this histological difference, such fibers are very similar in general structure to ordinary bast fibers. *Phormium tenax* is a native of New Zealand, but is also found distributed in other

portions of Australasia such as Norfolk Island; it has been introduced into several European countries, and is also cultivated to quite an extent in California.[1] The fiber of New Zealand flax is very white in color, is soft and flexible, and possesses a high luster. In tenacity it appears to be superior to either flax or hemp, as is seen by the following comparative figures (Royle).

	Pounds
New Zealand flax	23.70
Flax	11.75
Hemp	16.75

Royle also furnishes the following figures for the breaking strain of similar ropes made from various fibers:

Fiber.	Breaking Strain, Kilos.
Coir	102
Gambo hemp	133
Sansevieria zeylanica	144
Cotton	157
Pita	164
Sunn hemp	185

The fiber of New Zealand flax is 40 to 60 ins. long, nearly white, fine, and rather soft for a leaf fiber. It is used as a substitute for sisal in binder twine, baling rope, and medium grades of cordage, and is made up largely in mixtures with Manila or sisal, except in the cheaper tying twines. By extra care in preparation and hackling, a quality is produced almost as fine and soft as the better grades of flax, and when thus prepared it may be spun and woven into goods closely resembling linen.

The leaves of *Phormium tenax* reach over 5 ft. in length,[2] and the fiber

[1] New Zealand flax was discovered during Captain Cook's first voyage in 1771. It has been introduced into the south of Ireland, where it grows luxuriantly; it is also cultivated as an ornamental garden plant in Europe. It has also been introduced for economic purposes into the Azores and California, both of which places yield a certain quantity of the fiber. The name Phormium is derived from a Greek word meaning a basket, in reference to the use made of its leaves by the New Zealanders. Though the fiber may be employed either alone or in combination with flax as a spinning and weaving material, its principal use is as a cordage fiber. Though of high tensile strength, being second only to Manila hemp in this respect, nevertheless it does not withstand alternate wetting and drying such as required for ship's cordage. It is, however, a very suitable material for the making of binder twine for reaping machines.

[2] The leaves are sword-like and from 5 ft. to 8 ft. long and from 6 ins. to 8 ins. wide, the fiber being distributed throughout the leaf as a support. The outer surface of the leaf is of a bright siliceous character and very hard. The other portions are also hard and difficult to remove. The leaves are cut with a sickle, about 6 ins. from the crown of the plant, and are tied in bundles averaging about 90 lbs. in weight. If cut nearer than 6 ins. to the root, gummy matter and strong red dye in the butt of the leaf deleteriously affect the fiber, as it is difficult under present conditions to

is separated by first scraping the leaves and then combing out the separate fibers. The bundles of fibers form filaments of unequal size, which are easily separated by friction. The fiber has considerable elasticity, but readily cuts with the nail (Dodge). No process of retting is necessary, as with the bast fibers. The method of preparing the fiber, however, is as yet very unsatisfactory, and could be much improved. The amount of fiber obtained under the present method of operating is from 10 to 14 percent on the weight of the leaves, although the latter contain as much as 20 percent of fiber.

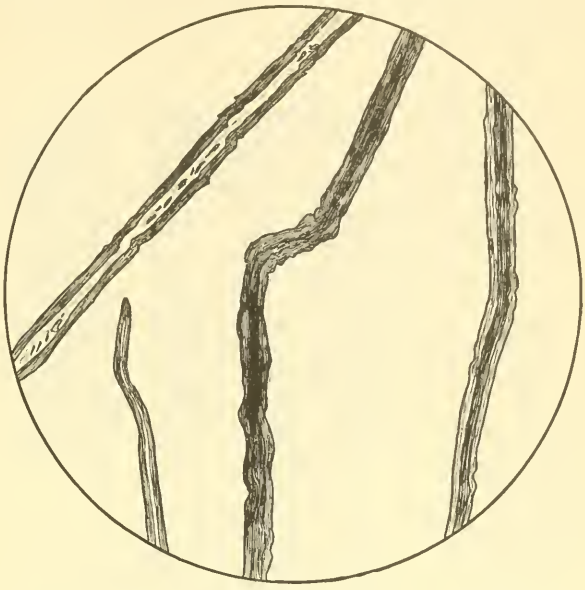


Fig. 329.—New Zealand Flax. (×300.) (Micrograph by author.)

In their microscopical characteristics the fibers of New Zealand flax are remarkable for their slight adherence. The fiber elements are from 5 to 15 mm. in length and from 10 to 20 microns in diameter, and the

eliminate the gum and color. When the trucks of phormium leaves reach the mill they are stacked in the yard to be sorted and prepared for stripping. In sorting, the leaves are graded into several qualities. They are also divided up into different lengths to be stripped separately, so that the fiber in each bundle may be as uniform as possible as regards both quality and length. The leaves weigh on the average about 17 ozs. each. In the work of stripping, several bundles are placed on a table or bench to the right of the operator, who feeds the machine with two or three leaves at a time. On leaving the stripper, the fiber is washed, and when fairly dry it is taken to the bleaching and drying fields, that its color may be made lighter or clearer by exposure to the weather.

In the next process any dry surplus vegetable matter which may still remain attached to the fiber is removed by the scutcher, which knocks off loose extraneous matter and the rough tail ends. The short fibers and the dust fall behind the drum, and after being well shaken to remove the dust and rubbish, constitute what is known as New Zealand tow, which is also exported and sells at a very fair price, as it contains many of the finest fibers. One of the things which is wanted, however, is a scutching machine which will make less tow or give a better yield of long fiber.

ratio of the length to the breadth is about 550. They are very regular and uniformly thickened, and the surface is smooth, though occasionally exhibiting wavelike irregularities in the cell-wall (Fig. 329). The lumen is very apparent, but is generally narrower than the cell-wall and is very uniform in its width. The ends are sharply pointed and not divided.

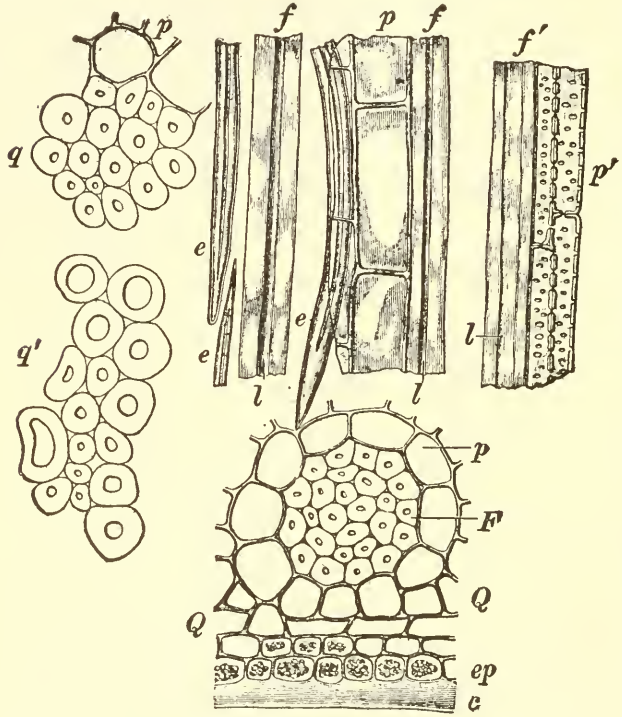


Fig. 330.—New Zealand Flax. *f*, Sclerenchymous bundles; *p*, parenchymous matter; *f'*, vascular fibers; *e*, fiber ends; *p'*, porous elements of vascular bundles; *q*, cross-section of bast fibers; *q'*, cross-section of vascular bundles; *Q*, cross-section of bast fiber bundle with accompanying elements; *cp*, epidermis; *c*, cuticle; *F*, bundle proper; *p*, parenchyma. (Hanausek.)

The cross-section shows rather loosely adhering elements and is very round in contour, the lumen being either round or oval, and is empty (Fig. 330). Fragments of parenchyma and epidermis are frequently to be noticed on the fibers. No median layer of lignin is apparent between the elements, though the fibers themselves are completely lignified. With iodine and sulfuric acid the fibers give an intense yellow coloration, with aniline sulfate a pale yellow, with chlor-iodide of zinc a yellowish brown, with ammoniacal solution of fuchsine a red; with Schweitzer's reagent the fibers are rapidly separated into their elements, but do not dissolve. The purified fiber of New Zealand flax is rather difficult to distinguish microscopically from aloe hemp or from *Sansevieria* fiber, except by the rounded and separated cross-sections. The fiber also usually contains a substance derived from the sap of the leaf, which possesses the peculiarity of giving a deep red color with concentrated nitric acid. The composition of the fiber is as follows (Church):

	Percent.
Ash	0.63
Water	11.61
Gum (and other matter soluble in water)	21.99
Fat	1.08
Pectin bodies	1.69
Cellulose	63.00

New Zealand flax is principally employed in the making of cordage and twine and floor-matting, though the best fiber can also be woven into cloth resembling linen duck. It has been used extensively in the United States for the making of "staff," being mixed with plaster for this purpose.[1] The chief drawback of the fiber of New Zealand flax is its poor resistance to water.

24. Marine Fiber.—This is a recent product obtained by dredging in the shallow water of a gulf in South Australia. Chemically it is a hydrated lignocellulose, giving the typical reactions of lignin. Microscopically it is very similar to New Zealand flax. From this it is to be concluded that the fiber is not of marine origin, but has been produced by the natural retting of a land plant, which has become submerged by the sea. Owing to its lignified character it dyes directly with basic dyes and some acid dyes, but has little affinity for substantive dyes. The fiber is brittle and has but little strength.

Marine fiber has its origin in the leaves and stem of *Posidonia australis*. It is a submerged marine flowering plant, and the enormous beds of the fiber which have been discovered appear to be due to the covering of the dead bases of the leaves and stems by the shifting sand which serves to preserve the fiber from decay. In the mass it is pale brown and somewhat lighter in color than cocoanut fiber. It is estimated that the workable areas of South Australia alone would furnish 4,500,000 tons of the material. Structurally the marine fiber filament is a complex of fiber aggregates resolvable into a congeries of longitudinal strands, each of which may be distintegrated further into ultimate fibers averaging about one millimeter in length. The filaments themselves are composed of comparatively coarse and short staples, tapering with occasional swellings from a thick to a fine end. They are rough, have a low degree of cohesion, have but little luster and possess a harsh feel. The tensile strength per unit area of cross-section is somewhat less than that of jute, but owing to the occurrence of many flaws its practical strength is much less. Its elasticity under steady longitudinal pull is very high, but its flexibility is very low. In its chemical nature marine fiber appears to consist of a

[1] This material is extensively employed for the building of temporary structures. It was used on most of the structures of the Columbian Exposition at Chicago, and at the Expositions at Buffalo, St. Louis and San Francisco.

lignocellulose compound intermediate in character between jute and wood fiber. The phloroglucinol value is exceptionally high, and the color reactions in general are those of a lignocellulose more reactive than jute. The fiber has a marked resistance to dilute alkalies, zinc chloride solution, and Schweitzer's reagent. It is readily acted on by halogens and has an unusual affinity for dyes. The fiber yields 55 percent of cellulose by the chlorine-sulfite process. The properties of the fiber, as demonstrated by the studies of Read and Smith, are opposed to its use in the manufacture of fine textiles. While it is inferior to jute in flexibility and tensile strength, it is greatly superior in its resistance to chemicals and bacterial agents. It is being employed quite extensively as an insulating material for heat.

In its microscopic appearance marine fiber is seen to consist of bundles of ultimate fibers or fibrils, firmly cemented together, and presenting the appearance of striated bands. Like hemp, the fibers show at intervals peculiar cross-markings or cracks. The individual fibrils, separated by steeping in chromic acid, exhibit a broad regular lumen and finger-shaped terminations. Chemically the fiber is a somewhat hydrated lignocellulose giving the typical reactions of lignin. Thus, with aniline hydrochloride it gives a bright yellow color; on boiling with phloroglucinol and hydrochloric acid it gives a crimson color; with ferric ferrocyanide it is colored dark blue; and on first steeping in chlorine water and then transferring to a solution of sodium sulfite it becomes red. With strong nitric acid it becomes reddish brown, a reaction which closely resembles that of New Zealand flax. The fiber as it comes on the market contains a considerable quantity of soluble chlorides (about 4 percent), doubtless derived from the sea-water. This, combined with a rather large ash content, makes the material rather non-inflammable. The dyeing properties of the fiber are rather peculiar; it shows the greatest affinity for the basic colors, with which it is readily dyed without a mordant, thus behaving like jute. With acid dyes that possess also residual basic qualities, such as Patent Blue and Alkali Blue, it also dyes fairly well, though not as well as wool.

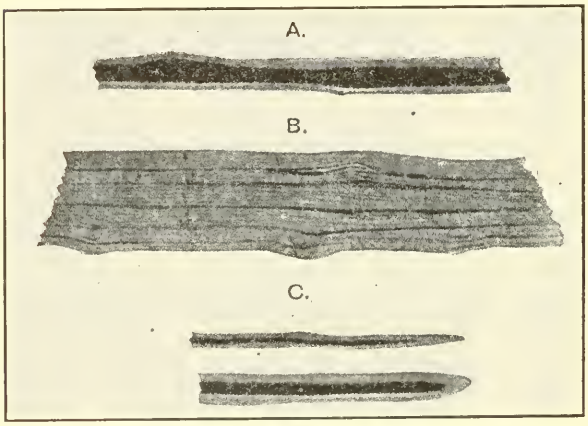


Fig. 331.—Marine Fiber. *A*, Single fibers; *B*, bundles of fibers; *C*, ends of fibers.

For the ordinary acid dyes, however, it shows no affinity at all. The fiber also shows but slight attraction for the substantive cotton or direct dyes and the sulfur dyes, differing in this respect from cotton.

Marine fiber has been used in Germany under the name of *posidonia*. It has been very successfully manufactured into yarns and fabrics by the Deutsche Faserstoff-Gesellschaft. After being brought to Germany the fiber is subjected by this concern to a chemical treatment for the purpose of softening it and making it resilient, the original fiber being stiff, harsh, and brittle. The staple of this fiber is declared to be equal to a medium-staple wool, and it is spun on the worsted and woolen system. It is characterised by elasticity and springiness, and the cloth which is made out of pure posidonia appears to show scarcely any creases. German cloth mills have mixed posidonia with wool or shoddy, and cloth of good strength and appearance has been obtained. It is believed that this fiber, by reason of its springiness, will have a wide field of use in the carpet industry. This raw material was sold at half the price of shoddy before the War; since the War none of this has been imported into Germany.

25. Manila Hemp.—This is the fiber obtained from the leaf-stalks of the *Musa textilis*, a variety of plantain which is a native of the Philippine Islands. The commercial supply of Manila hemp is obtained from the Philippine Islands; " cebu hemp " is a trade variety. In the Philippines the term *abaca* designates both the plant and the fiber obtained therefrom. Properly speaking *hemp* is the bast fiber obtained from the inner bark of the *Cannabis sativa*, whereas *Manila hemp* is entirely different, being the structural fiber obtained from the leaf-sheath of the *Musa textilis*.

The plant is cut down, stripped of its leaves and then sliced into narrow longitudinal strips which are scraped while still fresh until the fibers are exposed. After drying the fibers are beaten and are separated into three grades: (1) *Bandala*, the coarsest and strongest fibers from the outer portion of the trunk; (2) *Lupis* from the middle layers; and (3) *Tupoz*, the finest and weakest fibers from the inner part of the trunk.[1]

The abaca plants attain a height of 8 to 20 ft., the trunk being composed chiefly of overlapping leaf-sheaths. When the flower-bud appears, the entire plant is cut off close to the ground. The leaf-sheaths, 5 to 12 ft. in length, are stripped off, separated tangentially into layers a quarter of an inch or less in thickness, and these in turn split into strips 1 to 2 ins. in width. While yet fresh and green these strips are drawn by hand under a knife held by a spring against a piece of wood. This scrapes away

[1] Lupis and tupoz serve for the manufacture of fine native fabrics; while bandala is used for a coarse fabric known as *Guimara*, and more especially for cordage (see Semler, *Trop. Agric.*, vol. 3, p. 712; also Schanz, *Die Kultur des Manilahanfes auf den Philippinen; Tropenpflanzen*, 1904, p. 116).

the pulp, leaving the fiber clean and white. After drying in the sun the fiber is tied in bunches and taken to the principal towns or to Manila to be baled for export.

The reproduction of the abaca plant is usually by suckers, though it may also be carried on by seed. The first stalks are ready for harvesting twenty months to three years after planting, depending on locality and variety. After the first harvest it is usual to cut the plantation over every six or eight months. The mature plant consists of a cluster of ten to thirty stalks all growing from one root. The stalk is ready for harvest when the large violet flower bracts fall to the ground. Harvesting is done by hand with a sharp knife. The yield varies greatly, but 1000 lbs. of fiber per acre is considered a good crop.

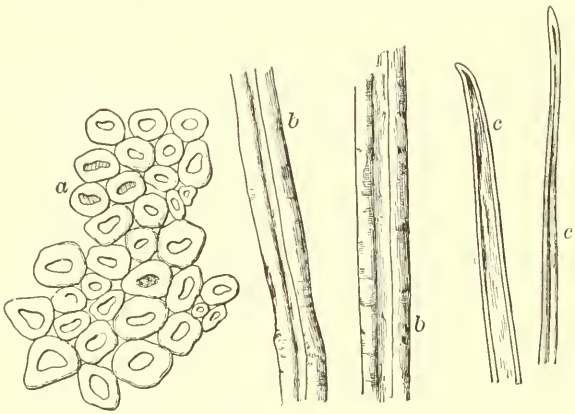


Fig. 332.—Manila Hemp. *a*, Cross-sections; *b*, longitudinal views; *c*, ends. (Cross and Bevan.)

A single plant yields about one pound of fiber. The fiber is white and lustrous in appearance, light and stiff in handle, and easily separated. It is also a very strong fiber, and of great durability. In the Philippines it is known as *abaca*. According to Carter, to extract the fiber from the leaves, the native first makes a slight incision just beneath the fiber at the end, and, giving a sharp pull, brings away a strip or ribbon of the outside skin containing the fiber. When a sufficient number of ribbons are thus obtained they are carried to the knife machine, of a most primitive character, consisting of a rough wooden bench with a long knife blade hinged to it at one end and connected at the other to a treadle, by means of which the operator can raise the knife for a moment in order to insert one end of a fibrous ribbon, which, being twisted round a small piece of wood in order to afford a good hold, is dragged through between blade and block, and all the pulp, weak fiber, and pithy matter scraped off. The leaves must be drawn several times between the blade and the bench before the fiber is sufficiently clean. The unscraped end, which is held by the operator, is then scraped by a boy, the fiber being then cleansed by washing, dried in the sun, and packed for shipment. One man can clean about 50 lbs. of fiber per day.

The coarser fibers of Manila hemp are used for the manufacture of

cordage, for which purpose it is eminently suited on account of its great strength. The light-colored fibers are heckled and spun into yarns for coarse weaving, such as the making of market-bags, etc. The finer grades are also used sometimes for the making of coarse upholstery goods. A considerable quantity of Manila hemp is now sent to Japan where it is manufactured into Tagal hat braid which is then exported chiefly to the United States where it is used for women's hats.

The best grade of Manila fiber is of a light buff color, lustrous, and very strong, in fine, even strands 6 to 12 ft. in length. Poorer grades are coarser and duller in color, some of them yellow or even dark brown, and lacking in strength. The better grades are regarded as the only satis-

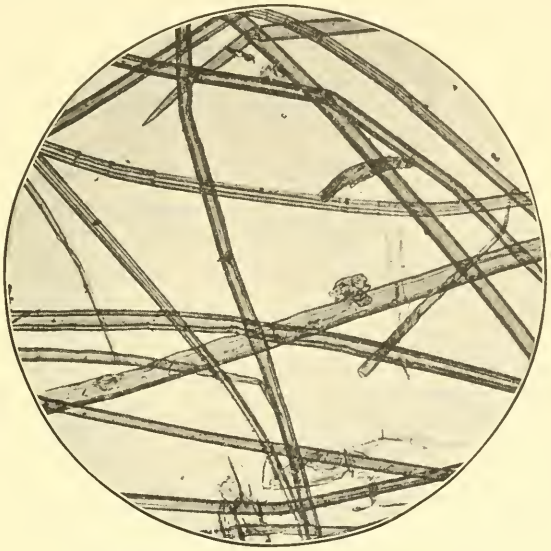


Fig. 333.—Manila Hemp. (Herzog.)

factory material known in commerce for making hawsers, ship's cables, and other marine cordage which may be exposed to salt water, or for well-drilling cables, hoisting ropes, and transmission ropes to be used where great strength and flexibility are required. The best grade of binder twine is made from Manila hemp, since, owing to its greater strength, it can be made up at 650 ft. to the pound as compared with 500 ft. for sisal. The grading of abaca as prescribed by Philippine law is based on color, tensile strength, and cleaning. There are four classes: excellent, good, fair, and coarse, and each of these are subdivided into a total of twenty-one grades of definite description.

The relative strengths of rope made from English hemp and that made from Manila hemp are about 10 to 12 respectively. The finer fibers which

require to be selected and carefully prepared, are woven into a very high grade of muslin, which brings a good price even in Manila.[1]

Under the microscope Manila hemp shows fiber elements of 3 to 12 mm. in length and 16 to 32 microns in width, the ratio of the length to the diameter being about 250. The bundles of fibers are very large, but by treatment with an alkaline bath are easily separated into smooth, even fibers. The fibers are very uniform in diameter, are lustrous, and are rather thin-walled. The lumen is large and distinct, but otherwise the fiber does not exhibit any markings. The cross-sections are irregularly round or oval in shape, and the lumen in the section is open and quite large and distinct (Fig. 332). The fiber bundles frequently show a series of peculiar, thick, strongly silicified plates, known as stegmata. Lengthwise these appear quadrilateral and solid, and have serrated edges and a round, bright spot

[1] The imports of Manila hemp into the United States during 1903 were more than 500,000 bales of 270 lbs. each. The following is the importation of Manila hemp into the United States from 1909 to 1911:

Year.	Direct from Philippines, Bales.	Via Europe, Bales.	Total, Bales.
1909	775,643	10,563	786,206
1910	594,724	2,736	597,460
1911	554,912	986	555,898

Eight bales are counted as a ton.

The following table shows the exports of Manila hemp from the Philippines since 1899.

Year.	Weight, Long Tons.	Value, (Millions.)	Average Price.
1899	70,152	8	$113.99
1900	90,869	13	146.81
1901	126,245	16	126.55
1902	113,284	19	170.29
1903	139,956	22	157.19
1904	123,583	22	169.48
1905	130,437	22	166.80
1906	104,078	20	188.44
1907	117,241	20	167.94
1908	131,382	17	125.61
1909	167,953	17	100.60
1910	163,173	16	100.97
1911	148,202	14	97.74
1912	175,137	22	126.05
1913	119,821	22	176.27
1914	116,386	19	164.93
1915	142,010	21	150.27
1916	137,326	27	194.35
1917	169,435	47	276.26

in the center. The stegmata may be best observed after macerating the fiber bundles in chromic acid solution; they are about 30 microns in length. On extracting the fiber with nitric acid, then igniting, and adding dilute acid to the ash so obtained, the stegmata will appear in the form of a string of pearls, frequently in long chains with sausage like links, a very peculiar and characteristic appearance (Fig. 334). The lumen often contains a yellowish substance, but no distinct median layer is perceptible between the fibers. Manila hemp is a lignified fiber, and gives a yellow color with aniline sulfate; iodine and sulfuric acid give a golden yellow to a green color; caustic soda colors the fiber a faint yellow and causes a slight distension; ammoniacal copper oxide causes a blue coloration and a considerable swelling. Manila hemp may be distinguished from sisal by the color of the ash, that of the former being of a dark gray color, whereas sisal leaves a white ash. According to Müller, the composition of Manila hemp is as follows:

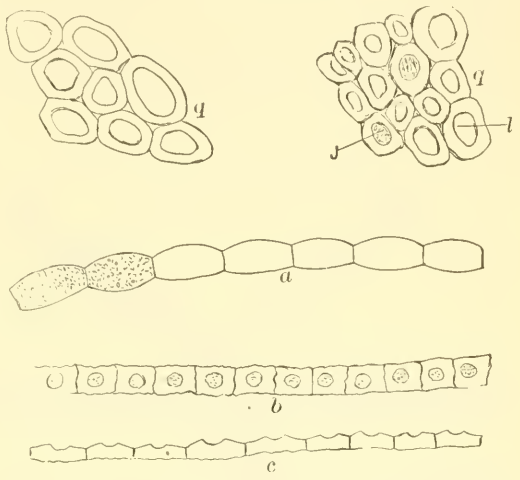


FIG. 334.—Manila Hemp. *q*, Cross-sections; *l*, lumen without contents; *J*, lumen containing granular matter; *a*, silicious skeleton of the stegmata; *b*, rows of stegmata, flat side; *c*, the same, narrow side. (Höhnel.)

	Percent.
Ash	1.02
Water	11.85
Aqueous extract	0.97
Fat and wax	0.63
Cellulose	64.72
Incrusting and pectin matters	21.83

Besides the *Musa textilis*, the fiber from the following varieties is also utilised: *Musa paradisiaca*, *M. sapientium*, and *M. mindanensis* from India and islands in the Pacific Ocean; *M. cavendishi* from China; *M. ensete* from Africa. The *M. sapientum* is the common banana plant or plantain. According to Dr. Royle, who experimented with some Indian varieties of the structural fiber, its strength is very satisfactory. His results are as follows: A Madras specimen bore a weight of 190 lbs., while one from

Singapore stood 360 lbs., and Russian hemp bore 190 lbs. A 12-thread rope of plantain fiber broke with 864 lbs., when a single rope of pineapple broke with 924 lbs. Compared with English and Manila hemps, a rope $3\frac{1}{4}$ ins. in circumference and 2 fathoms long gave the following results. The plantain, dry, broke at 2330 lbs. after immersion in water twenty-four hours; tested seven days after 2387 lbs., and after ten days' immersion, 2050 lbs. Manila and English hemp, dry, gave 4669 and 3885 lbs., respectively.

In the extraction of the good fiber from the abaca there is a great deal of waste produced. It has been suggested to use this waste for the manufacture of Manila paper which is now made principally from old Manila rope. The first experiments in this line, however, were failures as the waste had only a relatively low percentage of paper fiber and its quality was too variable; also the freight charges were prohibitive. Later investigations in this direction, however, promise better results, for, according to *Commerce Reports*, in 1912 twelve large paper manufacturers in eastern United States formed a Philippine corporation to handle and develop the use of abaca and its by-products in the paper industry. The enterprise rests upon the demand for certain classes of paper of an especially strong and tough grade. Experts report that a 1-in. strip of hemp paper will support 100 lbs. For a number of years there has been a growing demand among manufacturers for the waste products of hemp and old rope to supply this grade of paper, especially as the business of making paper bags for cement, flour, and similar commodities was being extended. The organisation backing this industry has spent over half a million dollars in experiments but reports as yet no substitute for hemp. The peculiarity of Manila hemp is that it is practically all fiber in composition, and that no

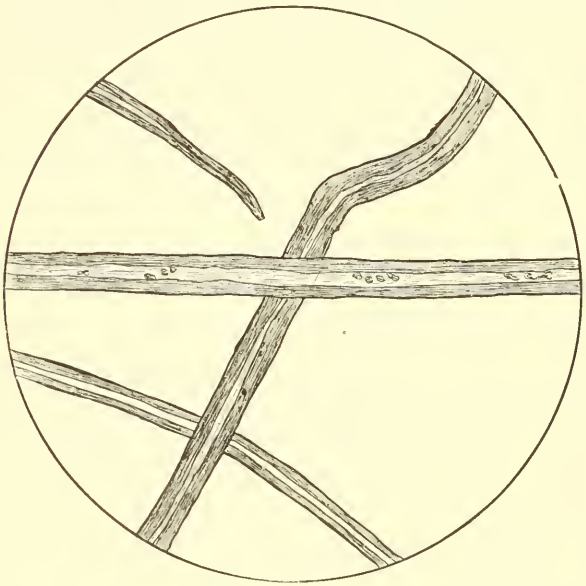


Fig. 335.—Manila Hemp. (×300.) (Micrograph by author.)

matter how finely the hemp is divided it is still capable of division as fiber, while a fiber of cotton, for example, is only a tiny tube, a fiber of sisal is merely non-fibrous wood, and similar objections are had to other products. The result has been the conclusion that, all things considered, the use of the whole of the original hemp stalk will be the most economical way out of the situation. By present methods about one-third of the ordinary plant is lost in stripping and about one-third of the remainder is not used for the reason that the fibers are too small and too weak to be of commercial use. The new plan is to take the entire hemp plant as cut on the plantation and merely crush, dry, and clean it in especially designed machinery.[1]

The Bureau of Plant Industry of Washington gives the following results of numerous tests made on the breaking strength of Manila hemp, together with some other hard fibers. These tests were made on a special machine designed for testing individual fibers. The results are given in the following table:

Weight and Breaking Strain of Hard Fibers

Fiber	The Weight per Yard, Grains.	Breaking Strain per Strand, Grains.	Breaking Length in Yards.
Abaca (Manila hemp), *Musa textilis:*			
Highest	0.567	46.6	82.2
Lowest	0.962	31.0	32.2
Average	0.772	34.8	45.0
Henequen (Yucatan sisal), *Agave fourcroya*	0.765	16.7	21.8
Sisal (Hawaii and East Africa), *Agave sisalana*	0.616	22.7	38.4
Cantala (Manila maguey), *Agave cantala*	0.429	9.6	22.3
Phormium (New Zealand hemp), *Phormium tenax*	0.659	18.8	28.5
Zapupe Vincent (*Agave lespinassei*)	0.722	21.5	29.7
Cabuya (from Costa Rica), *Furcraea cabuya*	0.574	20.0	32.2

[1] See Glafey, *Die Rohstoffe der Textilindustrie*, p. 72, for descriptions of the portable machine of Duchemin (*Ger. Pats.* 197,658 and 199,082) and Boenkens machine (*Ger. Pat.* 171,237).

CHAPTER XXIV

MINOR VEGETABLE FIBERS AND PAPER FIBERS

1. Sisal Hemp.—This is the fiber obtained from the leaves of the *Agave rigida,* a native of Central America; it is also grown in the islands of the West Indies and in Florida.

The fiber of the *Agave* was probably used by the ancient Mexicans and Aztecs. Cloth woven from this fiber was known as "nequen," and it is interesting to know that the Yucatan name for the commercial sisal hemp at the present time is "henequen."

The commercial supply of sisal hemp is produced in Yucatan, only small quantities being grown in Cuba and the Bahamas. According to Semler the natives cultivate seven varieties of the plant of which *Chelem* (*A. sisalana*), *Yascheki* (*Agave sp.*), and *Sacci* are the most important, while *Cajun* or *Cajum* (*Fourcroya cubensis*) and *F. gigantea* yield only coarse fibers. Gürke,[1] however, has shown that *Agave rigida* and its variety *sisalana,* as well as *A. elongata,* yield true sisal hemp, while *Fourcroya gigantea* (*F. fætida*) yields Mauritius hemp, which previously was regarded as a product of certain species of Aloe.

The true sisal hemp of Florida is the *Agave rigida,* but there is also a false sisal hemp from Florida, which is frequently confused with the other. This false sisal hemp is obtained from *Agave decipiens,* which is found wild along the coast and Keys of the Florida peninsula. There is considerable difference in the habit of *A. decipiens* and *A. rigida;* the former throws out its mass of leaves from the top of a foot-stalk the leaves radiating like a star, and the color being in strong contrast with the surrounding vegetation (Fig. 336). The true sisal plant, on the other hand, sends up its leaves from the surface of the ground. The leaf of the *A. decipiens* is also shorter and narrower, and nearly always rolled in at the sides, so that the cross-section appears like the letter U; the color is a bright green, the leaf also possesses very strong and sharp spines. The leaf of the *A. rigida* is flatter in shape, has a dark green color, and is without spines (Fig. 337). With respect to the fiber of the two varieties, that of the *A. decipiens* is whiter, finer, softer, and greatly deficient in strength. Tampico hemp, or Mexican fiber, is obtained from another variety of

[1] *Notizbl. k. Bot. Gartens,* Berlin, 1896, No. 4.

Agave known as *A. heteracantha.* It is a structural fiber like the others derived from the leaves. It is stiff, harsh, and bristle-like though pliant, and is used as a substitute for animal bristles in the manufacture of cheap brushes. The parenchyma or pith of the leaf squeezed out in the extraction of the fiber is used as a substitute for soap, as it possesses remarkable detergent properties. In Mexico the fiber is commonly known as " istle."

Sisal has a light yellowish color, and is very straight and smooth; it is principally used for making cordage, for which purpose it is quite valuable, as it is second only to Manila hemp in tensile strength. The fiber is easily separated from the leaf, and does not require a retting process. In their microscopical appearance the fiber bundles often show an interlaced formation with a peculiar spiral vessel and parenchyma cells containing single calcium oxalate crystals, which are often quite large (Fig. 338).

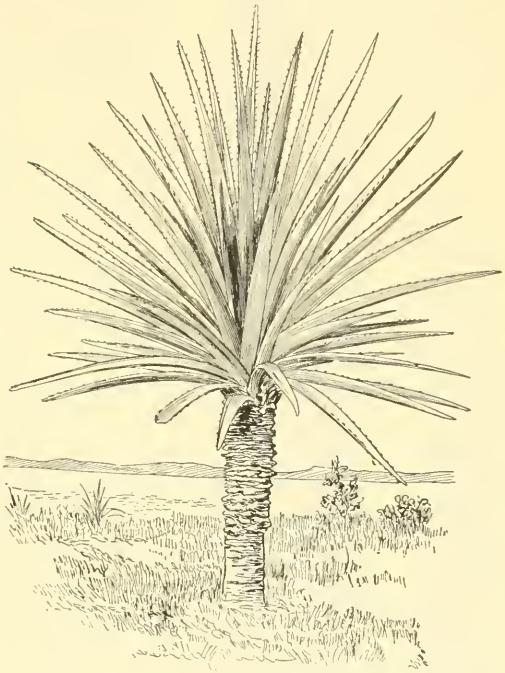


Fig. 336.—Florida Sisal Hemp. (Dodge.)

Sisal hemp is cleaned from the leaves by machines which scrape out the pulp and at the same time wash the fiber in running water. It is then hung in the sun to dry and bleach for from one to three days, after which it is baled for market. More than 600,000 bales, averaging about 360 lbs. each, were imported by the United States during 1903. Sisal fiber of good quality is of a slightly yellowish color, $2\frac{1}{2}$ to 4 ft. in length, somewhat harsher and less flexible then Manila hemp, but next to that the strongest and most extensively used hard fiber. It is used in the manufacture of binder twine, lariats, and general cordage, aside from marine cordage and derrick-ropes. It cannot withstand the destructive action of salt water, and its lack of flexibility prevents it from being used to advantage for running over pulleys or in power transmission. It is extensively used in mixtures with Manila hemp.[1] It is also used for the making of brushes and as a substitute for horsehair.

[1] *Yearbook,* Dept. Agric., 1903.

Beadle and Stevens[1] give the following table showing the relative strength of sisal and various rope-making fibers:

Fiber.	Breaking Strain of Thread in Grams.	Calculated Cross-section in Sq. Mm.	Breaking Strain, Grams per Sq. Mm.	Breaking Strain, Tons per Sq. In.	Breaking Length, Kilometers.
Sisal	1375	0.0240	57,300	36.2	38.2
Sansevieria	1289	0.0224	57,540	36.6	38.4
Manila	1655	0.0181	91,430	58.0	60.9
Hedychium	828	0.0093	89,300	56.7	59.1
Cotton fiber	8.2	0.00026	31,458	20.0	22.8
Cellulose monofil.	294	0.0140	21,000	13.3	14.0
Strong paper	....	....	....	....	10.0

The fiber elements of sisal hemp are from 1.5 to 4 mm. in length and from 20 to 32 microns in breadth, the ratio of the length to the diameter being about 1 : 100. They are usually quite stiff in texture, and show a remarkable broadening toward the middle. The width of the lumen is frequently greater than that of the cell-wall. The ends are broad, blunt, and thick, but seldom forked. The cross-sections are colored yellow by iodine and sulfuric acid, and show no evidence of a median layer between the elements. The sections are polygonal in outline, but often have rounded edges, and the bundles are usually close together. The lumen in the cross-section is large and polygonal in shape, though the edges of the lumen are more rounded than those of the walls. Short thick-walled fibers with short-pointed ends are present in large numbers in sisal hemp. They show a narrow lumen and distinct surface pores.

The ash obtained from the ignition of the fiber shows the presence of glistening crystals of calcium carbonate, which are derived from the original crystals of calcium oxalate to be found clinging to the fiber bundles. They are usually in longitudinal series, about 0.5 mm. long, and taper off at the ends to a chisel shape, resembling a thick needle in form, but having a quadrilateral cross-section. The occurrence of these crystals is very characteristic of this fiber. On the coarse fibers employed for the manufacture of brushes the crystals may frequently be seen with the naked eye.

Other fibers often confounded with true sisal are those derived from the *Furcræa cubensis* (cajun) and *F. gigantea* (giant lily). These plants are closely allied to the aloe and agave and grow extensively throughout tropical America. The fiber from the first mentioned is largely produced in Trinidad and its cultivation there has met with considerable success.

[1] *Jour. Soc. Dyers & Col.*, 1914, p. 94.

The green leaves yield about 2 to 3 percent of good fiber, clean and of fair color and equal or even superior to sisal in quality. The *Furcraea gigantea* is the basis of a considerable fiber industry in South America and Mauritius. It is known as *Aloes vert* and the green leaves yield about 3 percent of the fiber, which is known under the name of fique. It is largely used for the making of bags, horse blankets, fish nets, and similar coarse fabrics. A considerable quantity has been exported to the United States and Germany.

A *B*

FIG. 337.—True and False Sisal. *A*, Leaves of true sisal hemp plant; *B*, leaves of false plant showing thorny edges. (After *Bulletin* U. S. Dept Agric.)

2. Aloe Fiber or Mauritius Hemp.—This is obtained from the leaf of various species of aloe plants growing in tropical climates. The principal plant employed for Mauritius fiber is *Fourcroya fœtida*. In Porto Rico it is known as *maguey*, but is not to be identified with the Mexican fiber of the same name; in Hawaii it is called *malino*, which is probably a corruption of *manila*. The only locality in which the fiber is produced commercially is the island of Mauritius. This fiber is often confounded with that of the *Agave americana*, but it is of different origin. Aloe fiber, however, is very similar to *Sansevieria* fiber, and is hardly to be distinguished from it in either physical or microscopic appearance. The fiber elements are from 1.3 to 3.7 mm. in length and from 15 to 24 microns in breadth. Although uniformly broad, the cell-wall is thin. The fibers are usually cylindrical and not flattened; they show occasional fissure-like pores (Fig. 340). The cross-sections are polygonal, with slightly rounded edges. The lumen is usually somewhat broader than the walls, and in the cross-section is polygonal with rounded sides (Fig. 341). In the *Sansevieria* fiber the lumen in the cross-section is usually larger, and the cell-walls consequently thinner; furthermore the lumen has a sharp-edged polygonal form.

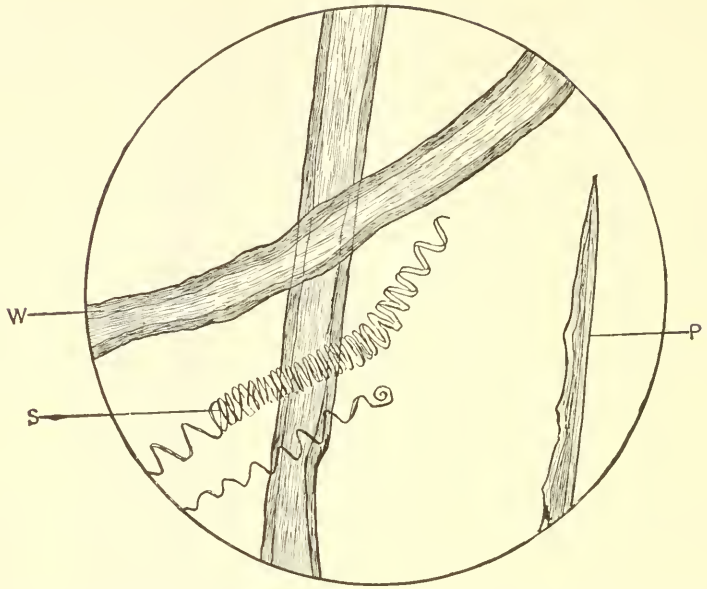


Fig. 338.—Sisal Hemp. (×300.) *W*, Cell-wall; *P*, end of fiber; *S*, spiral-shaped sclerenchymous tissue. (Micrograph by author.)

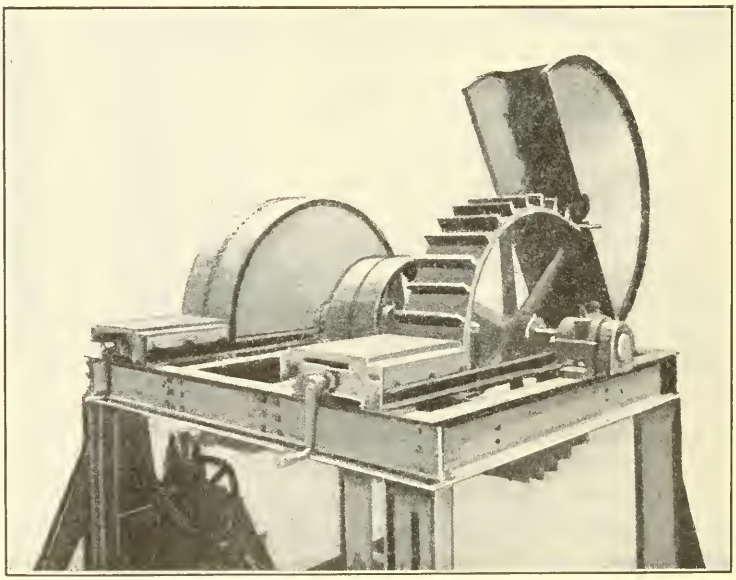


Fig. 339.—Decorticating Machine for Sisal.

The commercial supply of aloe fiber is obtained from Africa. The fiber is whiter and softer than other hard fibers, but it is weaker than sisal. It is used in the manufacture of gunny bags, halters, and hammocks, but more largely for mixing with Manila and sisal in making medium grades of cordage. When the better grades of cordage fiber (Manila and sisal) are abundant and quoted low in the market, Mauritius is likely to fall below the cost of production.[1]

3. Pita Fiber is obtained from the leaf of the *Agave americana* or century plant; it is also known as aloe fiber.[2] The *Agave* is a genus of fleshy-leaved plants belonging to the *Amaryllidaceæ*, chiefly found in Mexico and Central and South America. They are called "century" plants because they are supposed to flower but once. From some of the Mexican species there is obtained a distilled liquor known as *mescal*, also the fermented beverage called *pulque*. The fiber from *A. americana* (maguey plant) is a structural fiber composed of large filaments readily separated by friction. According to Spon the agave requires about three years to come to perfection, but it is exceedingly hardy, easy of cultivation, and very prolific, and grows in arid wastes where scarcely any other plant can live. It perishes after inflorescence, then

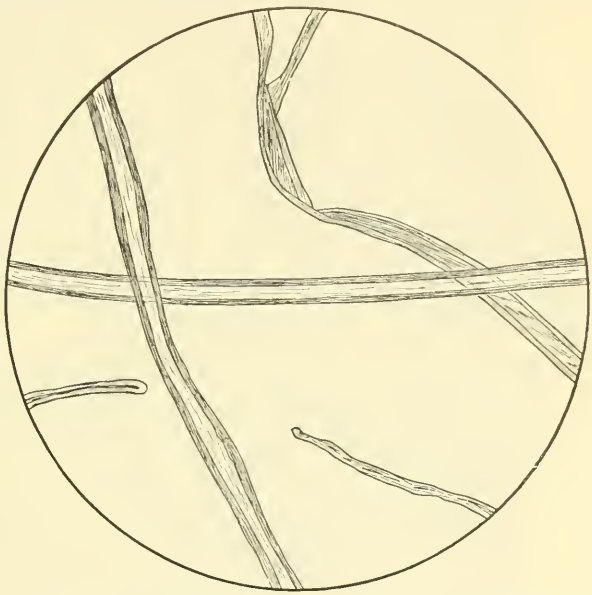


FIG. 340.—Mauritius Hemp. (×300.) (Micrograph by author.)

[1] *Yearbook*, Dept. Agric., 1903.

[2] The term "pita" is applied to several fiber plants in Central and South America, including sisal hemp. The Columbian Pita is a plant of the natural order *Bromeliaceæ*, a species of *Ananas*. In habit it resembles a very large pineapple plant and when mature it bears 20 to 40 leaves, which reach a height of 10 ft. The natives extract the fiber mechanically by scraping away the non-fibrous matter with a stick. The fiber is used locally for making fishing nets and thread. The only obstacle at present in the way of the commercial production of pita fiber is the lack of a machine for the successful extraction of the fiber from the leaves.

sends up numerous shoots. In Mexico 5000 to 6000 plants may be found on an acre; the average number of leaves is 40, each measuring 8 to 10 ft. in length and 1 ft. in width, and yielding 6 to 10 percent by weight of fiber.

The pita fiber is from 3 to 7 ft. in length. According to Spon its main faults are the stiffness, shortness, and thinness of the walls of the individual fibers, together with a liability to rot. Watt states that it takes color readily and freely, is light, and contracts under water rapidly. Dodge states that a distinctive characteristic of the pita fiber is a wavy or crinkled appearance which prevents the bundles of fibers in mass from lying closely parallel, as in the case of sisal hemp and similar straight fibers; another marked peculiarity is its great elasticity.

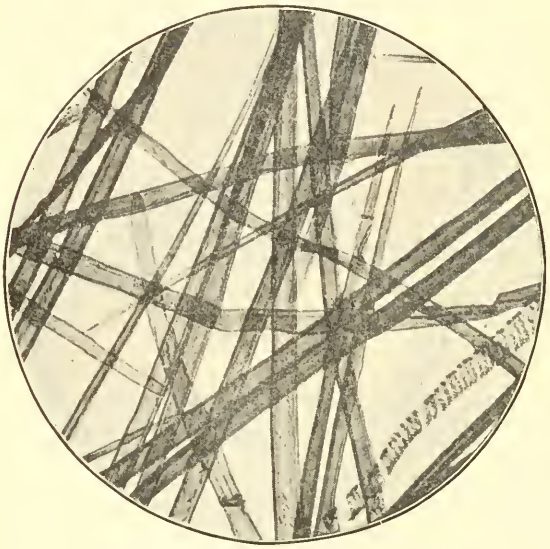


FIG. 341.—Mauritius Hemp. (Herzog.)

There are several varieties of agave fiber, which are known by their Mexican or Indian names. The best known of these are the *henequen* (*Agave saxi*), the *ixtle* (*Agave americana*), and the *lechuguilla* (*Agave heteracantha*). The last named is also known as Tampico or Matamoros hemp.

The fiber of Tampico hemp is stiff, harsh, but pliant and bristle-like; it is used as a substitute for animal bristles and for the making of cheap brushes. The fiber as obtained from the leaf is from 18 ins. to 2 ft. in length. The pith which is squeezed out in extracting the fiber possesses remarkable detergent qualities and is a valuable substitute for soap. According to Dodge the native name of the lechuguilla fiber is istle, though this name appears to have been used for fiber from a number of different species of plants; it is stated, however, that fully 90 percent of the istle fiber of Mexico is from the *Agave heteracantha*.

Henequen is principally grown in Yucatan, and was extensively used and highly prized by the ancient Mexicans, and still is at the present time. The fiber is white to pale straw in color, is stiff and short, has a rather thin wall, and furthermore is liable to rot. The fibers have a distinctive wavy appearance, and another peculiarity is its great elasticity. According

to Royle, Indian pita has been found superior in strength to either coir, jute, or sunn hemp, the breaking strain on similar ropes made of these materials being as follows:

	Pounds.
Pita	2519
Coir	2175
Jute	2456
Sunn hemp	2269

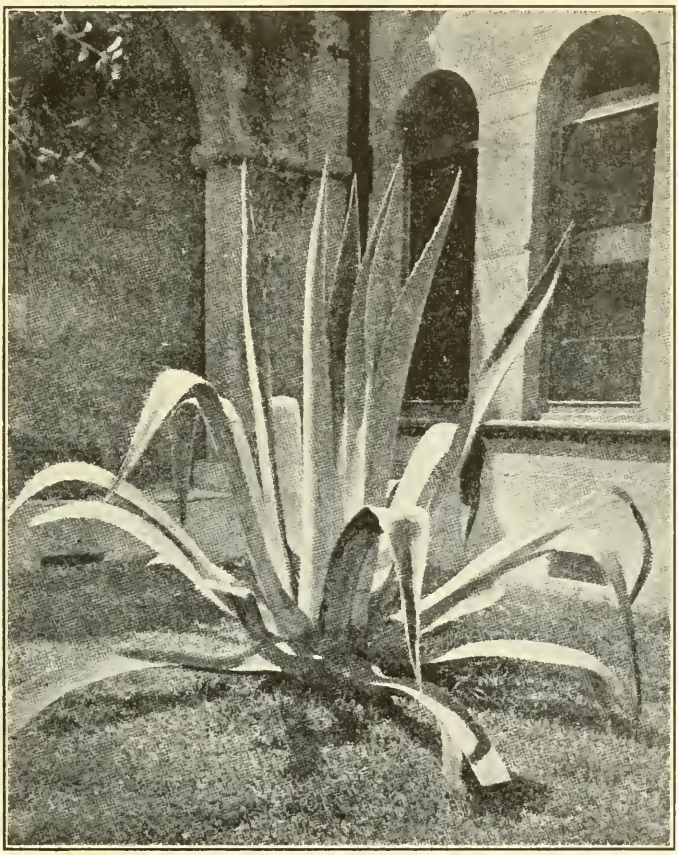


FIG. 342.—Century Plant. *Agave americana.* (Dodge.)

Russian hemp and pita, on comparison, gave a relative strength of 16 to 27. Besides its use as a cordage fiber, pita is also employed for the making of a very delicate and beautiful lace known as Fayal. In its microscopical characteristics pita is very similar to sisal hemp.

4. Pineapple Fiber or Silk Grass.[1]—This is obtained from *Ananas sativa* or pineapple plant. This fiber has great durability and is unaffected

[1] The term "silk grass," though applied to this fiber, is both meaningless and a misnomer.

by water. It is very fine in staple and highly lustrous, and is white, soft, and flexible. It is used in the manufacture of the celebrated *piña* cloth in the Philippine Islands. According to Taylor, a specimen of this fiber was subdivided to one ten-thousandth of an inch in thickness, and was considered to be the most delicate in structure of any known vegetable fiber. Microscopically it is distinguished from all other leaf fibers by the extreme fineness of its fiber elements. These are from 3 to 9 mm. in length and from 4 to 8 microns in thickness. The lumen is very narrow and appears like a line. The cross-sections are polygonal in outline and frequently flattened. The sections form in compact groups which are often crescent-shaped, and are enclosed in a thick median layer of lignified tissue. The fibers are accompanied by vascular bundles in which there frequently occur several rows of thick and strongly lignified fibers; consequently there are two classes of

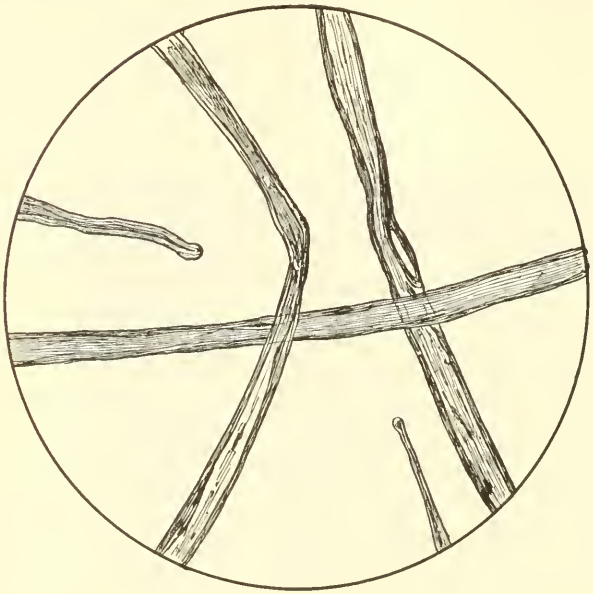


FIG. 343.—Pita Fiber. (×300.) *Agave americana.* (Micrograph by author.)

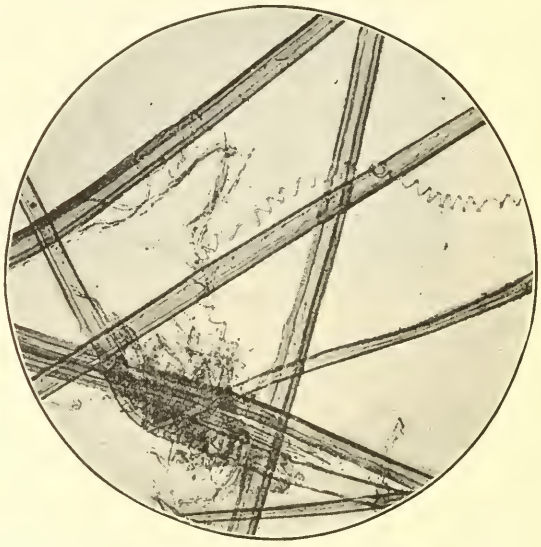


FIG. 344.—Pita Fiber from *Agave americana.* (Herzog.)

fibers to be distinguished: (1) long and extremely fine ones which are easily curled, with very narrow and frequently scarcely visible lumen, and with long, tapering, blunt, or, sometimes, almost needle-shaped ends, and (2) shorter fibers which though seldom thick are often stiff, and which occur in the vascular bundles and also are lignified throughout.

Arghan is the name given to a pineapple fiber recently brought to the attention of English fiber merchants, and considerable has been written about it in the technical press as a " new " textile material. It has been experimentally made into twine and rope and found to be eminently

FIG. 345.—Pineapple Plant. (Dodge.)

satisfactory, being of great tensile strength and highly resistant to seawater; it is claimed to be fully 50 percent stronger than hemp or flax. It has also been spun into fairly fine yarns and woven into cloth with considerable success. It has been suggested as a substitute for hemp and flax, as the fiber does not require any tedious retting process in its preparation, being simply obtained from the pineapple leaves which are readily split up into long silky fibers of a pearly white color. The fiber dyes and bleaches well and has a good luster.

5. Coir Fiber.—This is obtained from the fibrous shell of the cocoanut (Fig. 346). For the preparation of the fiber, the unripe nuts are steeped

in sea-water for several months, after which the fruit is beaten and washed away with water. The residual reddish brown fibrous mass is decorticated by tearing and heckling into fibers about 10 ins. in length. The fiber occurs in the form of large, stiff, and very elastic filaments, each individual of which is round, smooth, and somewhat resembling horsehair. It is principally used for making mats and cordage. It possesses remarkable tenacity and curls easily. In color it is cinnamon brown. It possesses marked microscopical characteristics; the fiber elements are short and stiff, being from 0.4 to 1 mm. in length and from 12 to 24 microns in diameter, the ratio of the length to the thickness is only 35. The cell-wall is thick, but rather irregularly so, in consequence of which the lumen has an irregularly indented outline (Fig. 347). The points terminate abruptly and are not sharp, and there appear to be a large number of pore-canals penetrating the cell-wall (Fig. 348). On the surface the fiber bundles are occasionally covered with small lens-shaped, silicified stegmata, about 15 microns in breadth. These stegmata fuse together on ignition, giving a blister on the ash. If the fiber is boiled with nitric acid previous to its ignition, the stegmata then appear in the ash like yeast-cells hanging together in the form of round, silicious skeletons.

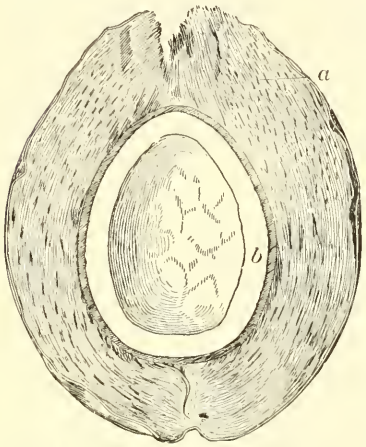


FIG. 346.—Section of Cocoanut. *a*, Husk containing fiber; *b*, the fruit or edible portion. (After *Bulletin* U. S. Dept. Agric.)

Coir gives the following microchemical reactions: with iodine and sulfuric acid, golden yellow; with aniline sulfate, intense yellow; Schweitzer's reagent does not attack the fiber. These reactions indicate a lignified fiber. According to Schlesinger, coir contains 20.6 percent of hygroscopic moisture.

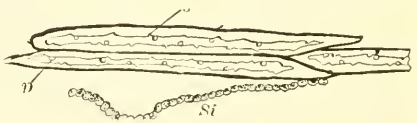


FIG. 347.—Coir Fiber. (×300.) *s*, Serrations in wall of lumen; *p*, pores in wall; *Si*, silicious skeleton from stegmata. (Micrograph by author.)

The cross-section of the fiber is oval in shape and yellowish brown in color, and enclosed in a network of median layers. Coir fiber is employed in the South Seas instead of oakum for caulking vessels, and it is claimed that it will never rot. The principal use for coir, however, is for cordage and matting. For cable-making it is said to be superior to all other fibers, on account of its resistance to water, lightness, and great

elasticity. It also has a great resistance to mechanical wear. Wright gives the following tests on various cordage fibers:

	Pounds.
Hemp	190
Coir	224
Bowstring hemp	316

Ceylon is the home and center of the preparation of coir fiber and yarn, from which cordage and coarse cloths are made, and the bristles are made into brushes. Galle, on the southwest of the island, is the chief seat of the native manufacture and its fiber is considered superior to the mill product. The cocoanut husks are thrown into a bamboo enclosure, which the natives have built in the sea, and after softening for six days in the water, the wood is pounded apart from the fibers with a stone, after which the fiber is heckled with a wooden comb and dried.

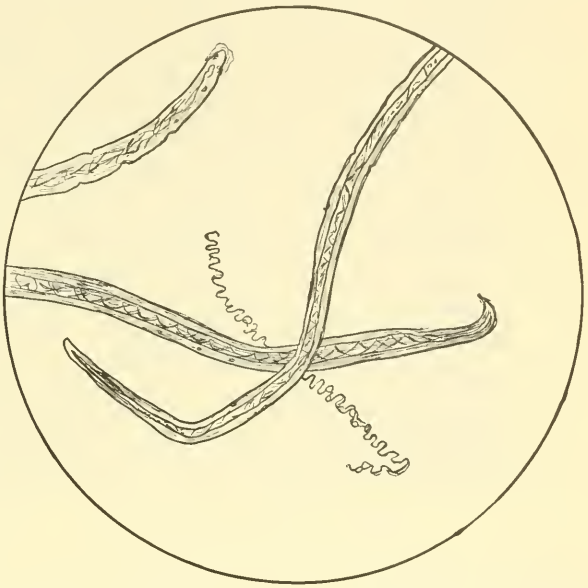


Fig. 348.—Coir Fiber. (×300.) (Micrograph by author.)

When the fiber is prepared by machinery the process is different; but the hand-prepared product is regarded as much superior. The husks are purchased by the bullock cart load at about 8 cents per hundred, or even for the cart hire. They are quartered and put in large water tanks and weighted with a network of iron rails. After five days the husks are removed and run through a machine composed of two corrugated iron rollers known as a breaker, which will crush them and prepare them for the next machine, called the "drum."

The drums are in pairs, a coarse one for the first treatment and a finer one for the second. They are circular iron wheels 3 ft. in diameter, which revolve at high speed and have rims about 14 ins. wide studded with spikes. The husks are held against the revolving drums and the spikes tear out the woody part, leaving the long, coarse fibers separate. The torn and broken fiber that falls from the drum spikes is fanned, then

dried by being spread out in the sun, and subsequently cleaned and baled as mattress fiber. The longer and stronger fibers are washed, cleaned, and dried, and then taken to a room where they are further heckled by women, who comb them through long rows of steel spikes affixed to tables.

The fibers are now in hanks about a foot long and as thick as a man's forearm. They are bound together, put into a hydraulic press, and baled for shipment as bristle fiber for making brushes, etc.

From the finer qualities of fiber used for mattresses there is spun what is known as coir yarn, in threads one-fourth of an inch thick and perhaps 50 ft. long. It is from these that a very superior rope and several kinds of coarse cloth are made. Coir yarn is manufactured chiefly at Galle, and is mostly shipped from that port with transshipment at London. On the local market there are two principal grades, the first grade known as Kogalla yarn, and the second as Colombo yarn. These two grades are subdivided into 15 to 24 slightly different standards, according to thickness, color, and twist. It is estimated that 1000 cocoanut husks will produce 70 to 80 lbs. of bristle fiber and about 300 lbs. of mattress fiber and yarn.

Besides the fiber from the husk of the cocoanut the leaf of the cocoanut palm also yields a fiber that has considerable use. The fresh leaves of the cocoanut palm are first boiled in water for a short time, and then torn apart into upper and lower halves. Then each half is torn by hand or suitable devices into strips of a suitable width. These strips are then boiled from one to two hours in a solution consisting of 5 to 8 lbs. of sodium carbonate, dissolved in 100 lbs. of water. After the above treatment, the material is washed once in clean water to eliminate various impurities. Then it is put in a bleaching solution made of 100 lbs. of water, 1 to 3 lbs. of sodium peroxide, 1 to 2 lbs. of potassium oxalate, and 50 to 100 grams of sulfuric acid, for a period extending over one to three days. During the infusion the material is stirred and disturbed from time to time. After the completion of the bleaching process the material is well washed by water and dried in the shade with a free exposure to air.

The strip of leaf thus treated rolls in from both edges when dried, and becomes a smooth, semi-transparent thread which is strong, elastic, light, and good-feeling, and, moreover, is quite waterproof. A hat or bonnet made of such thread does not become deformed or decolorised even after a long period of exposure and wear; and it is claimed that such hats are equal in quality to the true Panama hat. The threads may also be usefully employed in the manufacture of cloths, mats, bags, slippers, etc.

6. Istle Fiber.—This is otherwise known as Tampico fiber, and is obtained from the leaves of several species of Mexican plants which are principally found in the desert table-lands of northern Mexico (Fig. 349). The most important istle fibers are *Jaumave lechuguilla, Jaumave istle, lechuguilla, Tula istle, Palma samandoca,* and *Palma pita.* The principal

plants yielding the fiber are *Agave heteracantha, A. lechuguilla,* and *Samuella carnerosana.*

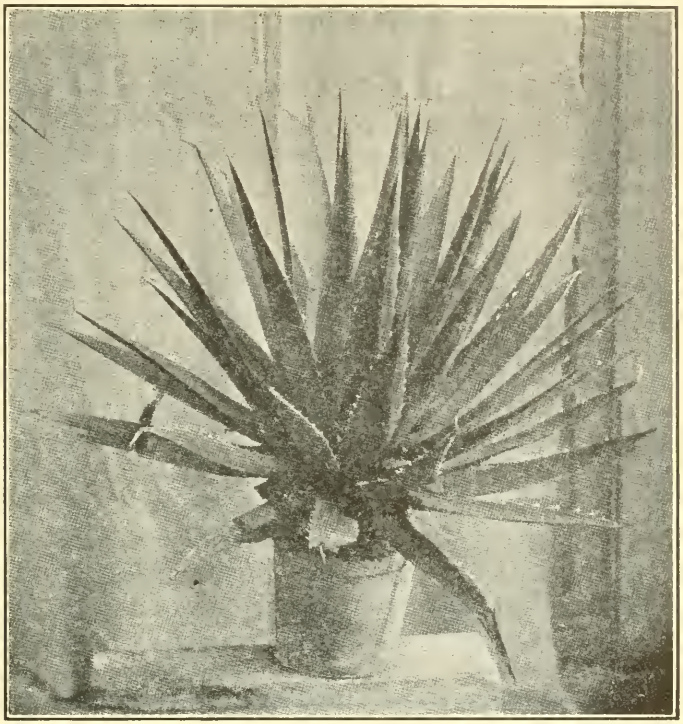


Fig. 349.—Tampico Hemp Plant. (Dodge.)

Palma istle fiber is 15 to 35 ins. in length, usually coarser and stiffer than sisal, yellow in color, and somewhat gummy. Tula istle is 12 to 30 ins. long and nearly white in color. Jaumave istle is 20 to 40 ins. long, rarely longer, almost white, and nearly as strong and flexible as sisal.

Fig. 350.—A Leaf of *Agave heteracantha.* (After *Bulletin* U. S. Dept. Agric.)

The importations of istle fiber into the United States had increased from less than 4000 tons in 1900 to more than 12,000 tons in 1903. Istle fiber has long been used as a substitute for bristles in the manufacture of brushes, and it is now being employed in increasing quantities in the cheaper

grades of twine, such as lath twine, baling rope, and medium grades of cordage. Introduced at first as an adulterant or substitute for better fibers, it seems destined to find, through improved processes of manufacture, a legitimate place in the cordage industry. If machines are devised for cleaning this fiber in a satisfactory manner, it is thought that the thousands of acres of lechuguilla plants in western Texas may be profitably utilised.

Istle fiber is used largely for making brushes; it is also made into cordage and woven into coarse sacks for containing grain. The commercial fiber is from 12 to 30 ins. in length, and is coarse and harsh.[1] The color of the fiber is deep yellow, but on boiling with water this coloring matter is almost altogether removed. The parenchymous tissue separated from the fiber is used as a substitute for soap, and even the commercial fiber gives a soapy solution when boiled with water.

7. Nettle Fiber.[2]—This fiber is used to some extent for spinning, being cultivated for this purpose in certain parts of Germany and in the province of Picardy in France. The product known by the specific name of nettle fiber is obtained from two species of the stinging nettle,[3] *Urtica dioica* and *Urtica urena*. The *Bœhmeria* (see Ramie and China grass) are also nettle plants, but belong to the stingless variety. The *Urtica dioica* yields the largest amount of fiber, but of large diameter and very thin cell-wall; the fibers from the second species, *Urtica urena*, are much smaller in diameter and have a thick cell-wall, resembling linen fibers to a great extent; its chief drawback is the small yield of fiber from the plant.

The nettle fiber appears to consist of pure cellulose, with occasional traces of lignin on the surface. It gives the following microchemical reactions: (*a*) with iodine-sulfuric acid reagent, blue coloration;[4] (*b*) with

[1] Imitation horsehair, according to a recent French patent, may be prepared from Tampico fiber by digesting 100 parts of the material for six hours under the pressure of three atmospheres with a solution consisting of 23 parts by volume of caustic soda solution of 36 Bé. and 1500 parts by volume of water. After rinsing the fibers are steeped for fifteen minutes in a bath containing one part of sulfuric acid per 100 parts of water. They are then washed, dried and put through a carding machine. For a bleached product the material is steeped for about eight hours in a solution of 800 grams of bleaching powder per 100 liters of water before the treatment with acid. Curly fibers are obtained by steeping the degummed fibers in a solution of caustic soda at 18° Bé. for about an hour.

[2] See Wiesner, *Rohstoffe des Pflanzenreiches*, vol. 2, p. 214; Möller, *Die Nesselfaser, Polytechnische Zeitung*, 1883; Höhnel, *Mikroskopie der Faserstoffe*, p. 52; Dodge, *Useful Fiber Plants*, p. 323.

[3] The stinging nettle is also common in the United States; it grows principally on waste lands. It has not been used as a fiber plant in this country, however. In Sweden it is cultivated to some extent for its fiber, being known as Swedish hemp; it is used for cordage, cloth, and fish-lines. In India it is known as *Bichu* or *Chiru*, meaning scorpion or stinger.

[4] The lumen of the fiber, especially toward the ends, is often filled with matter which gives a yellow color with this reagent.

ammoniacal fuchsine solution, no coloration; (*c*) with sulfate of aniline, no coloration; (*d*) with chlor-iodide of zinc, bluish violet coloration; (*e*) with chlor-iodide of calcium, rose-red coloration.

The fibers of *Urtica dioica* vary in length from 5 to 55 mm. (Vétillart) and in diameter from 0.020 to 0.080 mm. Under the microscope the fibers are characterised externally by fine oblique striations; the ends of the fibers are finely pointed. According to Höhnel, in its microscopic characteristics the nettle fiber is very irregular and unevenly marked, creased, and in part ribbon-like in form. The lumen is wide, and often contains a yellow substance. The ends are tapered, rounded off, and many times split or forked. The cross-section is oval, flattened, or even has the walls turned in. The latter are thin and are stratified in a pronounced degree, the inner layers frequently being marked radially.

The cross-sections of the fibers are oval and show thin cell-walls, which, however, at times may become quite thick, owing to irregularities in the structure of the fiber. The fiber is supple, long, and soft to the touch; like ramie it possesses great resistance to water; it is, however, comparatively weak in strength, owing to the thin cell-wall and irregular structure.

Fig. 351.—Nettle Fiber.

On account of the thin cell-wall, the nettle fiber gives only faint colorations when viewed under polarised light. In Germany the nettle fiber is spun into a greenish colored yarn known as *Nesselgarn*, this is woven into a cloth called *Nesseltuch*, which may be bleached to a pure white, and much resembles linen cloth.

During the War much was said and written in Germany about the cultivation and use of the nettle fiber for textile manufacture, but it may be assumed that the experiments made were not very successful, as but little is heard to-day of the use of the nettle fiber. The difficulties of cultivating the nettle would probably be as great as those of cultivating flax, and it would seem better to improve and develop the latter plant, the characteristics of which are so well known, rather than to attempt the development of a new plant industry.

The best specimens of textile nettles are found in the tropics and include the *Urtica capitata*, growing to the height of 3 to 5 ft., and the *Urtica chamædryoides*, which is from 6 to 30 ins. in height and plentiful in the United States.

The use of the nettle as a textile fiber dates from very early times.

The Egyptians and the ancient Scandinavians used it. The account of the third voyage to the coast of Kamchatka states that the natives used the nettle fiber to make rope, twine, and sewing thread. The ancient records note the use of the nettle in Germany and Russia. It was also known in Italy and France during the Middle Ages. The Encyclopedia of the eighteenth century contains an article on the production and use of the nettle, which states that it is manufactured into yarn in Germany. About the same period experiments with the nettle were carried on in Angers and Mons with very satisfactory results. At the beginning of the nineteenth century there was a permanent trade in nettle goods carried on in Picardy, Germany, and Sweden.

During the past century there have been numerous attempts to cultivate and use the nettle, including Bartoloni in Tuscany, 1809; by Edward Smith in England, 1810; and by Withlow in the United States, 1814. Among those who engaged in this work it is necessary to include a number of Frenchmen, the Abbé Rozier, 1793; Chalumeau, 1803; Chaumeton, 1818; Lardier, 1820; Chatin, 1861; Eloffe, 1869; Barot, 1891; d'Astanieres, 1894; Michotte, 1895. The Abbé Provenchir, 1862, reported that the nettle was used in Canada in the manufacture of cloth and cordage. At the Paris Exposition in 1878 Japan exhibited a large collection of nettle fibers, yarn, and fabrics. Experiments in nettle culture have been made for some years on plantations in Russia.

The appearance of the nettle fiber varies with the method of extraction. After decorticating the bark in the green state, the fibers are in the form of a greenish ribbon, harsh to the touch, about 60 ins. long and containing more or less woody matter according to the thoroughness of the decortication. These filaments rapidly assume a reddish gray shade and in that condition it is difficult to distinguish them from ramie or green hemp. The combed fibers are in the form of regular filaments from 1 to $1\frac{1}{4}$ yds in length and free from woody matter. The green shade is more uniform and the fiber is flexible and soft to the touch, especially if the combs have been oiled. The material when degummed in the raw state is a yellowish white. When degummed and bleached, but not combed, it has the appearance of flax. The combed stock has an appearance similar to that of degummed ramie.

The retted fiber varies widely according to the method of retting that has been used. Retting in running water produces ribbons of soft fibers, lustrous, and the color of straw. When retted in standing water the color is a dirty gray, as is the case when the stock is retted in the fields. Certain precautions are necessary in working fresh nettle. The stinging nettle, growing 14 to 20 ins. high, is more irritant than the dioecious nettle, which grows to the height of 40 to 70 ins.

According to Dr. Grothe, 100 lbs. of green bark yield 46 lbs. after drying,

producing 32 lbs. of filasse, which in turn yields 20 lbs. of combed filasse. The extraction of the fiber by decortication is preferable to retting and the apparatus used for working ramie serves perfectly for the nettle fiber. The decortication should immediately follow cutting. It is difficult to decorticate the material if the fibers have been cut more than eight hours previously; at the end of twenty-four hours decortication becomes impossible. The strips of fiber obtained by decortication are dried or retted according to the process selected. The material is generally dried in the open air and the fibers are separated by degumming by chemical means or by retting.

The chemical process is similar to that used for ramie, the material being immersed in a solution of soap and hypochlorite of ammonia. The retting process is similar to that employed for flax, hemp, and similar materials. The nettle fiber is soft and flexible, the length varying from $\frac{1}{8}$ to 2 ins. It is in many respects like the ramie fiber.

8. Fiber of Urena Sinuata.—The plant from which this fiber is obtained is a small shrub growing generally in the tropics. In America it is known as Cæsar weed; in Venezuela it goes by the name of Cadilla. The bast fiber resembles jute in appearance, being yellowish in color, of considerable brilliancy, and also, like jute, deteriorating in moist air. The average length of fiber bundles is 6 ft. The fiber-cells, according to Wiesner, have a length of about 1.8 mm., and an average diameter of 15 microns. The lumen of the fiber is very irregular in width, but is mostly rather broad, though not so large as that of jute. With iodine and sulfuric acid the fiber gives a yellow color; aniline sulfate also gives a deep yellow, which indicates strong lignification; Schweitzer's reagent produces a strong swelling of the cell-wall. There may often be observed on *Urena* fibers, under the microscope, cells of parenchymous tissue containing crystalline deposits. The ash of the fiber also shows aggregates of calcium carbonate, a feature which distinguishes it from jute.

9. Sansevieria Fibers.—There are several species of plants of the *Sansevieria* group which are used for fiber purposes, of which the following are the principal varieties: *Sansevieria cylindrica*, known as Ifé hemp; it occurs in South Africa, and the fiber is used for cordage. It is said to be especially adapted for cordage used in deep-sea soundings. *S. guineensis*, known as African bowstring hemp, is grown in Guinea and in tropical America. The fiber somewhat resembles Manila hemp and is used for cordage. *S. kirkii*, known as Pangane hemp; it grows on the mainland opposite the island of Zanzibar; the fiber is very long and is used extensively by the natives. *S. longiflora*, known as Florida bowstring hemp; the fiber is strong and of very desirable qualities, and is said to be superior to sisal hemp. It is sufficiently fine to be employed as a spinning fiber. *S. roxburghiana* is grown in India, where it is known as Moorva. It gives

the true "bowstring hemp," as the fiber is highly prized by the natives for bowstrings on account of its great strength and elasticity. *S. zeylanica* is a species cultivated in Ceylon. The fiber is shorter than other varieties, but is largely used for making cordage, mats, and coarse cloth.

The *Sansevieria* fibers are all obtained from the leaves of the plants; these vary in length from 2 to 9 ft. The commercial fiber consists of a bundle of filaments. The fiber elements have a length of about 2 mm. and a diameter of about 20 microns, and are characterised by a large lumen. The fibers are lignified and are often accompanied by spiral-shaped cells of parenchymous tissue. In strength and durability *Sansevieria* fiber is almost equal to Russian hemp. The fiber of *S. zeylanica* is very similar to aloe or Mauritius hemp, and is often called "aloe hemp."

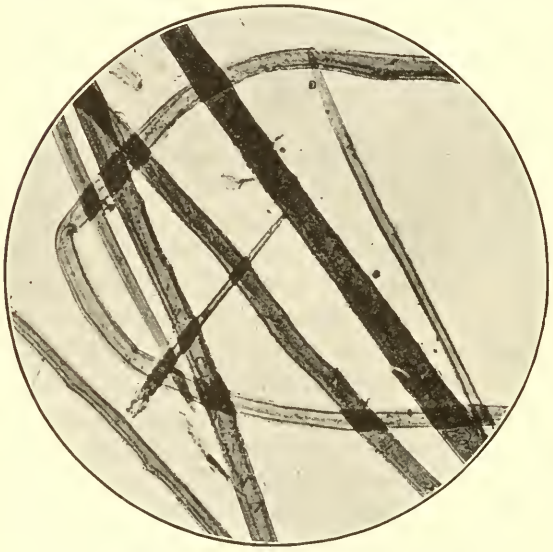


Fig. 352.—Sansevieria Fiber. (Herzog.)

10. Tillandsia Fiber. —This fiber, known as Spanish moss, is obtained from *Tillandsia usneoides*, and is extensively employed in trade as a vegetable horsehair, as it resembles very closely the animal product in general appearance, durability, and elasticity. The plant grows as a parasite on tropical trees, and the commercial product consists of the branched stems. It is of a greenish gray color and is covered with soft silvery-gray scales. The fiber is composed of a layer of bast in which are imbedded eight fiber bundles; by treatment with caustic alkali solution the nucleus (or stripped fiber) is easily separated. The stripped fiber has a jointed appearance, and from the joints side branches often issue. According to Wiesner the commercial fiber never has natural ends; the color varies from brown to lustrous black. The diameter between the joints varies from 120 to 210 microns. The diameter of the commercial fiber is from 0.3 to 0.5 mm. Microchemical color reactions cannot be obtained with this fiber owing to its dark color. Schweitzer's reagent has apparently no reaction. According to Wiesner the fiber of vegetable horsehair has 9.0 percent of moisture and 3.21 percent of ash.

According to Höhnel, the Tillandsia fiber consists of the many fiber-

bundles growing out of the young sprouts of the plants; it does not consist of air-roots, but of branches which have numerous leaves and small twigs. In the center of the branch, which is 0.3 to 0.5 mm. thick and whose nodes are 5 to 10 cm. (mostly 6 to 7 cm.) long, lies a sclerenchymous rope with the vascular bundles; it is from this that the fibers are derived. It consists of a ground-mass of rough, long, sclerenchymous elements, of which the inner are light brown, and the outer are dark brown. The former are short and thin, and 8 to 12 microns wide, while the latter are 15 to 18 microns wide and on an average 1.4 mm. long, though sometimes they also occur very short and only 2 to 3 mm. long. In this firm matrix are imbedded 8 vascular bundles, which consist of spiral, network, and ring-shaped fibers, thin-walled, colorless, woody parenchym, and cambium cells. Sieve-like rods appear to be lacking. Here and there, however, may be seen a kind of parenchymous rind with the epidermis resting on the fibers. This epidermis is highly characterised by its shell-shaped hair scales; these are made up of a single-cell layer, out of which grows a many-celled minute hair. The very thick outer walls do not permit a trace of cuticle to be observed. The scales are the organs of the plant for the

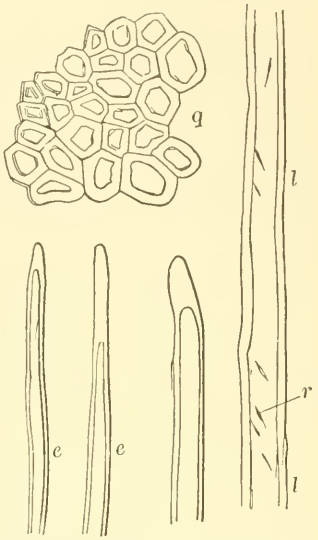


Fig. 353.—Fiber from *Sansevieria*. (×325.) *e*, Ends; *l*, longitudinal view; *q*, cross-section; *r*, fissure-like pores in cell-walls. (Höhnel.)

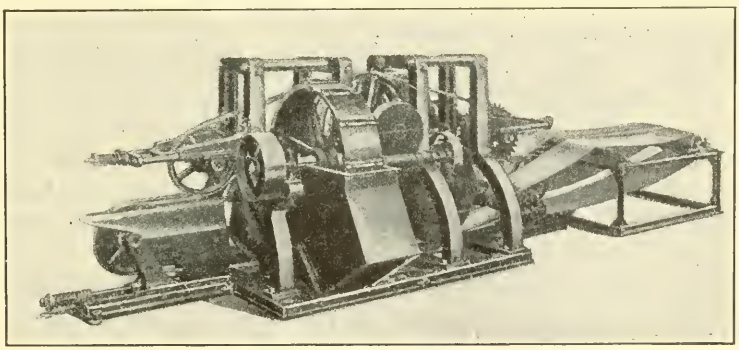


Fig. 354.—Decorticating Machine for *Sansevieria* Fiber.

absorption of water which roots do not have, but which are found on the twigs of plants.

11. Solidonia Fiber.—This is the name given to a vegetable fiber brought out in Germany as a wool-substitute. It is supposed to be a fiber derived from an African plant similar to China grass, and it seems to be very similar to ramie. It is a very fine fiber and has a screw-shaped form which makes it somewhat resemble wool. The length of the fibers varies from $2\frac{1}{2}$ to 4 ins. in length in medium grades, while the finer grades reach a length of 6 ins. According to Valdenaire, the solidonia fiber when examined under the microscope shows filaments having branches and striations, and also has a large central canal or lumen of a yellow color. The Vetillard reagent colors the fibers a greenish red, inclined to a violet. The fibers obtained from the nettle, which are somewhat similar to solidonia, are stained blue by the same reagent. In the raw state solidonia is of a gray color, similar to flax, but is bleached very easily. It acts the same as cotton in the presence of dyestuffs and the dyeing operation is the same. The property possessed by solidonia of absorbing perspiration without creating a sensation of cold on the skin, enables it to be mixed with wool to advantage in the manufacture of knit goods.

Solidonia is converted into yarn by either the carded woolen or worsted process and is spun by the worsted process not finer than 36's (cotton count). Up to the present time the material has been used for knit goods, passementerie, in mixtures with short wool for dress goods and cheviots and in mixtures with long wool for imitation worsted.

In Germany, solidonia gained a wide field of use on account of the shortage of wool during the War. As a substitute for linen, solidonia has been used in Germany for the manufacture of table linen of beauty and strength. It has also been used for machine belting. German hosiery and underwear mills have produced from it socks and stockings which are difficult to tear, and unshrinkable under wear, and sporting jackets of fine quality and strength.

The German woolen mills have manufactured an army cloth composed of 75 percent wool and 25 percent solidonia, which, it is asserted, surpasses in tensile strength any pure wool cloth. Similar results are claimed with respect to papermakers' felts, which, with a percentage of solidonia mixture, show a considerable increase in strength. Furthermore, women's and men's clothing composed of half solidonia and half wool or shoddy, especially in piece-dyed goods, have found a ready market. In textile circles in Germany it is declared that there is an unlimited field for the use of this fiber. Previous to the War the price of solidonia in Germany was two-thirds the cost of good staple wool.

12. Fiber of Sea Grass.—This is the fiber of *Zostera marina*, a seaweed or grass which is to be found extensively on the seacoast of temperate climates. The available fibers are from 1 to 2 ft. in length, and consist of bundles of 3 to 6 elements. The latter are about 3 mm. in length,

with a diameter of about 6 microns, hence they are of great fineness. They apparently consist of pure celullose.

The giant seaweed (*Macrocystis pyrifera*) may also be used as a fiber. this seaweed reaches great lengths, sometimes as much as 700 ft. and vast masses are often thrown up on exposed coasts. It is not, strictly speaking, a fiber plant but is locally employed for the making of rough cordage and fishing lines; it has great strength and is very durable.

13. Raphia.[1]—This fiber is obtained from the cuticle of the leaves of the raphia palm (*Raphia ruffia*), which grows extensively in Africa. The leaves are very long, the average being about 25 ft. The fiber

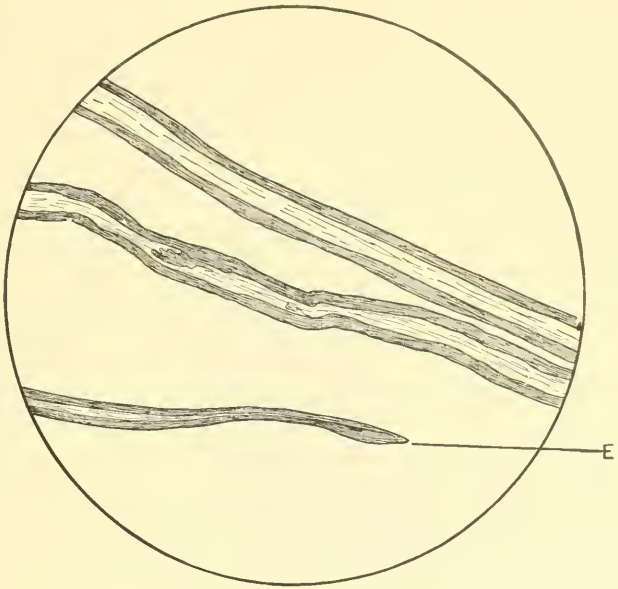


FIG. 355.—Raphia Fibers. (×300.) *E*, Showing spoon-like end. (Micrograph by author.)

occurs in the form of flat straw-colored strips, 3 to 4 ft. in length and about $\frac{1}{2}$ in. in width; from these ribbons (which are largely used for plaited textiles) the individual fibers may be separated as fine filaments. The fiber elements are about 1.7 mm., in length and 14 microns in diameter. Under the microscope the surface of the fiber appears irregular, owing to the occurrence of fragments of parenchymous tissue. The lumen is about one-fifth the diameter of the fiber. With iodine and sulfuric acid the fiber gives a yellow coloration; with chlor-iodide of zinc a similar color; with phloroglucinol and hydrochloric acid a reddish coloration. Schweitzer's reagent causes an irregular swelling of the fiber.

[1] Sometimes spelled "raffia."

A fiber somewhat resembling raphia in its ribbon-like appearance is that from the Great Macaw Palm (*Acromia lasiospatha*). In Brazil it is known as *Mucuja*, and in Cuba as *Pita de corojo*. According to Morris, the fiber is firmer than raphia and not so papery; it is extremely strong and is capable of being divided into very tough filaments. Dodge states that the ribbons are very white and by rolling between the hands may be broken up into innumerable filaments of great fineness. One drawback to its use is the presence of little spines, as sharp as needles and about half an inch in length. In Cuba the fiber is used for cordage, and is said to be equal to henequen, from which it can hardly be distinguished.

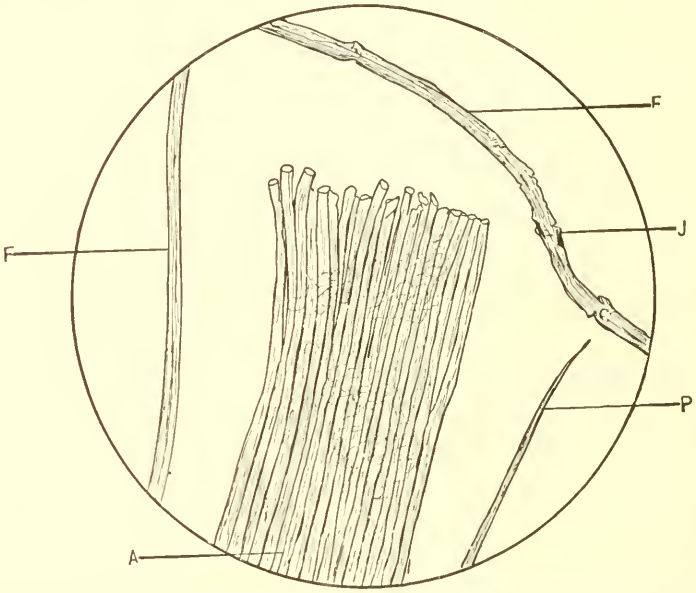


Fig. 356.—Fibers of *Bromelia karatas*. (×300.) (Micrograph by author.)

Another variety is the *Acromia sclerocarpa* or *Gru gru*, the fiber of which is distinguished by remarkable fineness and softness.

14. Bromelia Fibers.—The *Bromelia* is a genus of plants having very short stems and densely packed, rigid, lance-shaped leaves, the margins of which are armed with sharp spines; they are natives of tropical America, though also found in other tropical countries. The principal species which yield fiber are the following: *B. karatas*, *B. pinguin*, *B. argentina*, *B. fastuosa*, *B. sagenaria*, *B. sylvestris*, and *B. serra*. In Mexico the *Bromelia* is cultivated in parts as a textile plant and a fiber is obtained from it which is described as very fine and from 6 to 8 ft. in length. By reason of its fineness and toughness, it is used for making belts, and such

fabrics as bagging, wagonsheets, carpets, and also for cordage, hammocks, etc. The *B. pinguin* [1] is perhaps the best known of this class of fiber plants, and it is known as the wild pineapple; it is often mistaken for an allied species, the *B. sylvestris*, and many writers have confused both of these varieties with the fiber of the common pineapple. The wild pineapple fiber mentioned by Morris (of the Kew Gardens) as *B. pita* is really *B. karatas*.

The *B. argentina*, known as *caraguata*, is an allied species which is found in Argentina and Paraguay; its structural fiber is soft and silky and resembles pineapple fiber, occurring in lengths of from 4 to 6 ft. and of medium strength. The *B. sylvestris* [2] gives a structural fiber which is very long, creamy-white, fine, and silky; it is used in Central America for making hunting pouches and finely woven textures. The name of "silk grass" and "silk grass of Honduras" has been given to this species, but this is a rather indiscriminate name and is applied to a number of widely differing fibers. Some writers also refer to this fiber as the "istle" or "ixtle" of Mexico. This variety is also given the name *Karatas plumieri*,[3] and is commonly known as Mexican fiber, Honduras

[1] Dr. Baker gives the botany of *B. pinguin* as follows: Acaulescent; leaves 100 or more in a rosette, ensiform, stiffly erect in the lower half, reaching a height of 5 or 6 ft., 1½ to 2 ins. broad at the middle, tapering gradually to the point, green and glabrous on the face, thinly white-lepidote on the back, armed with very large-toothed pungent brown prickles; peduncle stout, stiffly erect, about a foot long, its leaves often a bright red; panicle dense, stiffly erect, 1 to 2 ft. long; axis and branches densely mealy; branch-bracts oblong, pale, lower with a rigid spine-edged cusp; lower branches 3 to 4 ins. long, bearing 6 to 8 sessile flowers; flower-bracts minute, ovate; ovary cylindrical, very pubescent, about an inch long; sepals nearly as long, with a densely matted tip; petals reddish, densely matted at the tip with white tomentum, about 1¼ ins. longer than the calyx; berry ovoid, yellowish brown, 1 in. in diameter.

[2] Dr. Baker gives the following description of the botany of *B. sylvestris:* Acaulescent; leaves ensiform, rigid, 3 to 4 ft. long, 1½ ins. broad, low down, narrowed gradually to the point, bright green on the face, thinly albo-lepidote on the back, armed with strong-hooked prickles; peduncle a foot or more long, its leaves reflexing, the upper bright red; inflorescence a narrow panicle with short spaced-out corymbose branches, all subtended by bright, red bracts, the lower with rigid spine-edged tips; ovary pubescent, cylindrical-trigonous, about an inch long; sepals nearly as long as the ovaries; petals reddish, not matted at the tip, protruding ¼ in. from the calyx.

[3] The botany of *Karatas plumieri* is described as follows: Acaulescent; leaves 30 to 40 in a dense rosette, rigid, spreading, ensiform, 4 to 8 ft. long, ½ to 2 ins. broad, low down, narrowed gradually to the tip, green and glabrous on the face, persistently white-lepidote and finely lineate on the back, armed with large pungent-hooked marginal prickles; flowers about 50 in a dense sessile central capitulum, at first 3 to 4 ins., finally 6 to 8 ins. in diameter, surrounded by reduced ensiform inner leaves tinged with red; flower-bracts, scariose, oblanceolate, 2½ to 3 ins. long; ovary cylindrical-trigonous, 1½ ins. long, clothed, like the bracts and sepals, with loose brown tomentum; sepals linear, permanently erect, an inch long; petals reddish, glabrous, exserted

silk-grass, and wild pineapple. The plant grows throughout tropical America, and the fiber is obtained from the leaf which grows to a length of 8 to 10 ft. and is armed with recurved teeth or spines. This fiber has been much confused with that of *Bromelia sylvestris.* The fiber appears to be used locally only for nets, cordage, sacking, etc. The fiber varies in quality according to the age of the plant, that from the young leaves being fine and white, while the older leaves give coarser fiber. It has been pronounced by some as being superior to Russian flax as a textile fiber.

15. Piassava.—This fiber is obtained from the piassava palm, growing chiefly in Brazil. There are, however, two varieties of piassava; the Brazilian is obtained from the leaves of *Attalea funifera,* while the African is obtained from the leaves of the wine palm, or *Raphia vinifera.*[1] In Brazil the piassava fiber is extensively used for the making of ropes, sails, and mats. At the present time it is also largely used in Europe for the manufacture of brushes, it being of the nature of a bristle, yet very flexible. The commercial fiber from Brazil has a length often as much as 6 ft.; according to Wiesner the breadth of the fiber is 0.8 to 3.5 mm. The color varies from light to dark brown. The individual bast cells are 0.3 to 0.9 mm. in length. Stegmata are often observed in the periphery, and on treatment with chromic acid the silicious matter is left in characteristic star-shaped residues. According to Greilach air-dried piassava contains 9.26 percent of moisture, and Wiesner found the ash to be 0.506 percent.

African piassava has less elasticity than the Brazilian product, and hence is of lower value. In cross-section under the microscope, the Brazilian fiber shows an aggregate of bundles, whereas the African piassava consists of a single filament. The commercial African fiber has a length

$\frac{1}{4}$ to $\frac{1}{3}$ in. beyond the tip of the sepals, united in a tube toward the base; fruit 3 to 4 ins. long, 1 in. diameter, pale yellow, with an edible white pulp, tapering from the middle to both ends; seeds globose, dull brown, vertically compressed, $\frac{1}{5}$ in. diameter.

[1] Coarse fibers occur in trade which are derived from a number of palms. They are employed partly as stuffing materials and partly for the making of brushes. To these fibers belong: (1) Piassave (Monkey grass, Paragrass, Piassaba) which is the fiber from the leaves of *Attalea funifera* in South America. It is coarse, 0.8–2.5 mm. thick, and is used for brushes, brooms, ropes, etc. (2) The palmetto fiber from *Chamaerops humilis* (*crin végétal, crin d'afrique*) in North America; prepared by splitting up the leaves; it is a grass-like material, and is used for packing and stuffing. (3) Fiber of the date palm, from *Phœnix dactylifera;* from the leaves; the fiber is light yellow in color, thick and stiff. (4) Talipot fiber from *Coryphæ umbraculifera* in India. (5) Raffia straw, the epidermis of the leaf shank of *Raphia tædigera;* used for twine and basket work; it consists of white, thin bands with turned-in edges. (6) Ejon or Gormito, from *Arenga saccharifera;* used in India for cordage; it is very similar to the (7) Kitool or Siam fiber from *Caryota urens;* a coarse, almost black fiber, used for brushes. (8) The black horsehair-like fibers from *Bactris tomentosa* and other palms; used for packing (Höhnel).

of about 60 cms. and a breadth of 1 to 3 mm. (Wiesner). The color varies from pale yellow to dark brown. The stegmata resemble those on the Brazilian fiber but are larger.

The Brazilian piassava fiber is obtained from the dilated base of the leaf stalks, which separates into a long coarse fringe. The fiber is stiff, wiry, and of a bright chocolate color. According to a circular of Ide & Christie (London fiber brokers), all of the harsher commercial brush fibers are classified under "piassava," the following forms being recognised: Brazilian, Bahia (*Attalea funifera*), and Para (*Leopoldinia piassaba*); kitool from Ceylon (*Caryota urens*); Palmyra also from Ceylon (*Borassus flabelifera*); West Africa (*Raphia vinifera*); and Madagascar (*Dictyosperma fibrosum*).

Another Brazilian palm fiber that has attracted considerable attention is that from the Tecuma palm (*Astrocaryum tucuma*). The fiber is obtained from the young leaves and is readily secured, as it lies just under the epidermis of the leaf, which is very thin and may be easily rubbed off, leaving the fiber clean and white. It is claimed that in strength the fiber is equal to flax, and the filaments are so fine that it has been given the name of "vegetable wool." It is used in Brazil chiefly for the making of nets, fish-lines, and hammocks. Another variety which is often confused with the foregoing is the so-called *Tucum thread* derived from the unopened leaves of the Tucum palm. It is a fiber of great strength and is highly prized for the making of bowstrings and fishing-nets by the natives; it is laborious to extract from the leaf, however, and brings a high price. The natives of the Upper Amazon make very beautiful hammocks of fine tucum thread, knitted by hand into a compact web of so fine a texture as to occupy two persons for several months in their completion (Wallace). The fiber is fine, resistant and durable, of a yellowish white color and very elastic, and capable of absorbing a large amount of water (Dodge).

Another palm fiber that is employed quite extensively in the East Indian Islands is that from the sago palm (*Arenga saccharifera*). It is horsehair-like material found at the base of the leaves and is the gomuti fiber or *Ejoo* of the Malays. It is used for making cordage, brushes, and for upholstery. According to Roxburgh, ropes made from the black fibers of the leaf stalks are exceedingly durable under water. The fiber is as elastic as coir and floats on water. It is also used for making sandals.

There are also a few other fibers known commercially as piassava, the principal one of which is obtained from *Caryota urens*. This is grown in India and Ceylon and is known by the name *kitool* or *kittul*. It is a brownish black fiber, and, according to Dodge, exhibits considerable tenacity and will bear twisting. The finer fibers closely resemble horsehair and may be readily curled. When employed for this purpose the fiber is combed and steeped in linseed oil to make it more pliable, when

it also assumes a black color. It is sometimes mixed with horsehair and used for stuffing mattresses and pillows. The chief use of kittool fiber, however, is for the making of brushes, for which it is especially suited; such brushes are used for polishing linen and cotton yarns and for brushing velvet. In Ceylon the fiber is also used for making ropes of great strength and durability and these are used for tying elephants. Considerable of this fiber has been imported into the United States where it is chiefly used for making brewers' brushes.

Crin végétal is also a palm fiber employed as a substitute for horsehair in stuffing. It is obtained from a dwarf palm in Algeria, *Chamærops humilis*. It is also imported under the name of *African fiber*. The plant is a species of palmetto and the fiber is obtained by shredding the leaves. It comes into trade in the form of a loosely twisted rope, which when opened up gives a crinkled fiber somewhat resembling hair. It is used as a mattress fiber.

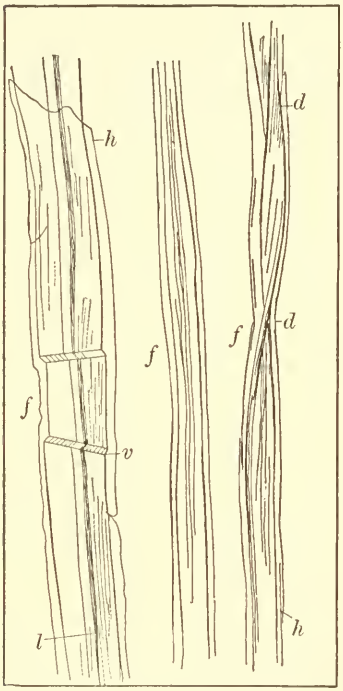


Fig. 357.—Paper Mulberry Fiber. Showing *d*, twists; *v*, cross-mark; *l*, lumen. (Höhnel.)

16. Paper Mulberry Fiber.—With regard to its textile uses this fiber is rather unusual in that it is employed by the natives of the South Sea Islands for the preparation of a fabric directly without spinning into yarn or weaving. The plant from which it is derived is a small tree known as *Broussonetia papyrifera* and the fabric, known as *tapa* (or *kapa* and also known as *masi* in Fiji) is made from the bast. This fabric is a very fine white cloth and the method of its preparation is rather curious; the cleansed fibers are laid out so as to form a regular and even surface, several layers being laid down wet and allowed to dry overnight. They will adhere so that the entire mass may be lifted as one piece. This web is then laid on a smooth plank and beaten with a wooden instrument until it is spread out and matted together in a strong web as fine as muslin. Pieces may be webbed together in a remarkable manner. In the Kew Museum is a part of such a fabric from the Friendly Islands said to be originally 120 ft. wide and 2 miles long. Some varieties of tapa cloth are made quite thick and resemble tough wash leather. The material may be readily dyed and printed and is easily bleached to a good white.

The paper mulberry also grows very extensively in Japan where the fiber is used for the making of paper. A kind of cloth is also made in Japan from this paper, the paper being cut into strips which are twisted into a yarn and used as the filling of the fabric, the warp consisting of hemp or silk.

According to Höhnel the fiber of the paper mulberry is about 6 to 15 mm. long and about 25 to 35 microns thick, though two kinds of fibers are usually present, thick and thin. The fiber is mostly thick-walled and is sometimes twisted somewhat like cotton. The lumen is small and difficult to distinguish, though at intervals it is filled with a yellowish material. In the ribbon-shaped fibers the ends are broad and rounded, while in the thick fibers the ends are smaller and tend to be sharply pointed. The fibers often show the presence of small prismatic crystals of calcium oxalate (Fig. 357).

17. Perini Fiber.—This is a fiber obtained from a plant indigenous to Brazil, and known as *Canhamo braziliensis perini*, being named from its discoverer Victorio Antonio de Perini, who found it in its wild state in the forests of Brazil. He studied its culture and practical value as a fiber for textiles and paper and received a U. S. patent for it in 1904. The plant is virtually a weed, growing from 12 to 18 ft. high in four to five months, and resembles hemp in general appearance. It was known as Brazilian linen and was once held forth as a possible competitor for linen. The plants grown for fiber should be cut before flowering, and require about three months to attain the proper growth of 10 ft. They are cut down about 4 ins. from the ground, and immediately send out shoots, which can be cut in the same manner again. In this way three crops may be obtained each year, after which the roots are dug up and seed sown for a fresh crop. The plant is hardy, resisting alike the dry and the rainy season, and is not a prey to insects or mildew. The fiber which is obtained from the bast is of excellent quality and closely resembles flax, being long, fine, strong and flexible, and easily adapted to bleaching and dyeing. Its luster is also quite high and the color is good. The fiber is easily decorticated from the stem of the plant and does not require a retting operation, but may be stripped entirely by mechanical processes. The perini fiber is cultivated to a considerable extent in Brazil and is employed in textile manufacturing in that country. If properly organised the industry of growing this fiber should be capable of great extension so that the fiber could be suitably prepared for the American and European market as a fiber to compete with linen and hemp. Attempts have been made to develop the perini fiber business in the United States with the idea of employing the entire stem of the dried plant as a paper making material. Some of the fiber has been quite successfully grown in the south, but as yet sufficient interest does not seem to have developed to

carry on the cultivation of it on a large scale. The present author has examined samples of this fiber and has tested them out in various ways, which leads him to the conclusion that the bast fiber could be employed in the textile industries as an excellent substitute for flax. It is said that about 3000 lbs. of fiber can be obtained per acre for each cutting of the plant.

18. Couratari Fiber.—This is a bark fiber employed rather extensively by the natives in South America to make a crude cloth for their rough clothing. Orton states that the natives make a bark cloth from the Tururi or *Couratari legalis*. The plant is a small tree with a white bark from which single pieces of fabric may be taken up to 4 yds. in length. The cloth resembles a coarse woolen fabric composed of two layers of wavy fiber. A similar fabric is made from the Tauary tree (*Couratari tauari*)

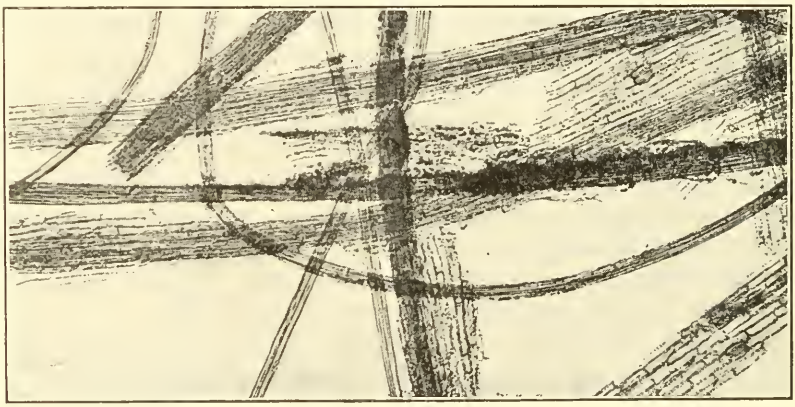


FIG. 358.—Peat Fiber. (Herzog.)

of Brazil. This is a larger tree from the interior bark of which thin layers of fabric are extracted, appearing like thin paper. It is much used for wrapping cigarettes and cigars and as a rough clothing and bedding for the natives. Blankets made from it resemble soft pliable leather. Some of the Indians of Peru and Bolivia make shirts of the fabric and dye them in various colors. The *Couratari guianensis* of Guiana also produces a similar textile fiber that is used for many purposes.

19. Peat Fiber.—The fiber obtained from certain varieties of peat has been utilised for textile purposes in Europe. It is usually mixed with wool shoddy or other low-grade fibers to make coarse yarns. The so-called "Geige" process for manufacturing peat wool consists in first stirring the dried peat in a bath of weak soda for several hours to remove the humic compounds. It is then dried and passed through opening machines, and afterwards subjected to a process of fermentation. The

fiber is then treated to a number of processes of extraction, washing and souring, and finally bleached. The product, which averages about 15 cm. in length, is said to be excellent for the preparation of surgical bandages as it is highly absorbent. It may also be spun with 50 percent of wool to give textile yarns.[1]

According to Linsbauer the fiber of peat is mostly derived from the leaf bast of various kinds of Eriophorum. The length of the fiber elements varies between 0.323 and 2.304 mm., the majority, however, being less than 1 mm. The diameter varies between 4.9 and 9.9 microns and the fiber has a long spindle-shaped form. It shows a broad and distinct lumen somewhat similar to jute, and the cell-wall has often a wavy appearance. When treated with phloroglucinol and hydrochloric acid the fiber gives a red color showing lignification. When treated with copper-ammonium oxide solution the fiber turns green in color and exhibits a remarkable sausage-like swelling somewhat similar to cotton.

20. Textile Yarns from Wood-pulp.—There is at present a considerable industry in the manufacture of yarns for twine and textile fabrics from wood-pulp. The wood-pulp tissue is cut into narrow strips which are then twisted on special machines so as to give a coarse yarn. These yarns are made in counts from 5 to 10 (cotton scale) and are possessed of sufficient tensile strength and elasticity to be manufactured into a wide variety of fabrics. Used alone, these wood-pulp yarns are made into floor coverings, bagging, wall covering, and various ornamental upholstery fabrics. They are especially adapted as a substitute for jute in such uses, for though they have not the tensile strength of jute, yet they exhibit great resistance to wear and rubbing.[2] When woven in conjunction with yarns of cotton, linen, jute, etc., a wide variety of fabrics may be cheaply produced.

The manufacture of yarns from wood-pulp allows of the utilisation in the purely textile industries of fibers not having sufficient length to be spun. The minimum limit of economic working in spinning is obtained with fibers of 3–5 mm. length, and as this is the maximum limit in the case of paper making, it may be seen that by converting paper into textile yarns it becomes possible to utilise for the latter fibers of any length.

There are several methods now in use for the manufacture of wood-pulp yarns:

[1] There has been considerable investigation in Germany on the subject of peat fiber. See *Zeit. f. d. Gesamte Textilindustrie*, 1899, Nos. 5 and 7; *Kunststoffe*, 1918, Nos. 9 and 11; *Dingl. Polyt. Jour.*, 1900, p. 437; Hausding, *Handbuch der Torfgewinnung und Verarbeitung*, Berlin, 1904; also see *Ger. Pats.* 50,304, 96,540, 92,265, 102,988, 150,698, 159,284, 162,108, 161,667, 161,668, 167,831, 168,172, 169,381, 180,397, 258,068, 301,394, 301,396, 307,765, 315,755.

[2] Paper yarn is used also as a substitute for jute as a packing between the armature of lead and iron in electric cables.

(*a*) The Claviez System[1] makes a yarn called *xylolin* from a finished but unsized paper. The paper is cut into strips of 2–3 mm. width, which are then wound on separate bobbins. A twisting and rolling is then given the paper strip[2] so as to consolidate it into a compact thread or yarn. The yarn is then moistened and again twisted and rolled to produce a more solid thread. *Textilose* is a similar product used as a jute substitute.

(*b*) The Kellner-Türk method[3] starts with the paper sheet in the unfinished condition as it is delivered from the press-rolls of the paper machine. The production of the pulp ribbons is effected by a specially constructed wire cloth consisting of a gauze alternating with flat strips of brass. The pulp ribbons are then rolled and twisted into a yarn.[4]

(*c*) The Kron system[5] produces products known as *silvalin* yarns. The pulp web is divided into narrow strips by fine jets of water. The entire web is rolled up and the strips afterward separated as disks. The pulp strips are then squeezed between press rolls for the gradual removal of water, then further dried on steam-heated cylinders. The strips are next wound on magazine rolls from which they are twisted and rolled into yarns. Silvalin yarns are now produced in large quantities in Germany and Russia where they are employed as substitutes for jute. *Licella* yarn is a similar product made from narrow strips of wood-pulp paper as a substitute for jute.[6]

According to Pfuhl[7] wood-pulp yarns have an average breaking length of 5 to 7 km., and an elasticity of 6 to 7 percent of their strength when moistened, but when woven into fabrics they may be waterproofed satis-

[1] *Ger. Pat.* 93,324. The Claviez method was worked at Jagenberg.

[2] In order to spin paper yarns, regulated moistening of the paper is necessary, and therefore some means of measuring the rate at which the material can be wetted is desirable (F. Herig, *Papier-Fabrikant*, 1921, p. 32). For this purpose, two pieces of very smooth cardboard are stuck together, the top piece having a hole cut in it in the form of some regular figure. The cavity is filled with a very finely powdered dye, and the paper to be tested is gently pressed on the surface so that it takes up a thin film of the dye. Any excess of the pigment is shaken off and the paper is floated on water with the dusted surface uppermost. As the paper wets through, the larger granules of dye show up like pepper and then two waves of color pass over the dusted surface. The time from the laying down of the paper to the appearance of the second wave of color is taken as a measure of the wetting property of the paper. Mahogany Red is the most suitable dye, as it contrasts well with the color of the wet paper. Methyl Violet may be used with advantage for lightly-sized papers since it takes twice as long to develop as Mahogany Red.

[3] *Ger. Pats.* 73,601, and 76,126, and 79,272. The Kellner-Türk process is carried out at Altdamm, Stettin.

[4] *Ger. Pats.* 140,011 and 140,012, and 140,666.

[5] *U. S. Pats.* 762,914 and 794,516; 762,640 and 762,641; 795,776 and 776,474.

[6] Licella yarn is made by the Süddeutschen Jutefabrik.

[7] Pfuhl, *Papierstoffgarne*, p. 101.

factorily.[1] The finished fabric has about one-half the strength of jute fabric of the same quality and weight.

The size or count of wood-pulp yarns is expressed by the number of meters to the gram. To convert this into the cotton count (840 yds. per lb.) multiply by the factor 0.691; to convert into the line count (300 yds. per lb.) multiply by the factor 1.654; and to convert into the jute count (lbs. per 14,400 yds.) multiply by the factor 29.

The manufacture of paper yarns and textile fabrics therefrom underwent a tremendous development in Germany and Austria during the recent World War. The paper used for spinning paper yarns is almost entirely made from wood-pulp. The yarns are made from long, narrow strips of thin paper, which can be loosely or tightly twisted or "spun." The yarns can be made of various thicknesses, and have now been employed for weaving a great variety of fabrics. They can be readily dyed to any desired shade, and certain kinds can be bleached to a snowy whiteness. In manufacturing the yarns, other materials have sometimes been combined with the paper, but recently the tendency has been to make them of paper only. In the production of fabrics, paper yarns are sometimes woven in conjunction with other yarns, such as those of cotton, flax, hemp, and jute.

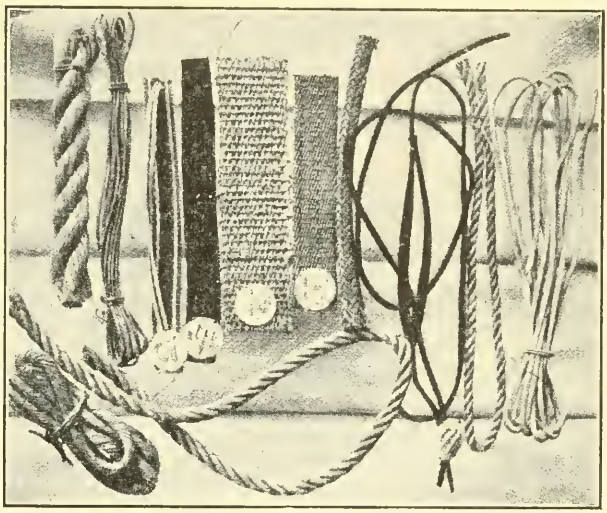


FIG. 359.—Twines Made from Paper Yarns.

Among the chief advantages of paper yarns are the low cost of production, which, at any rate in normal times, is much less than that of yarns

[1] For the waterproofing of paper yarn and its fabrics, a number of materials have been used, but the best method seems to be first to pass the yarn through a bath of gum, tannin and silicate of soda at 50° C., and then through a cold bath of basic formate of aluminium having a density of about 6° Bé.

Other materials that have been used include a treatment with gelatine, after which it is subjected to formaldehyde, but this has been found to reduce the strength and to cause the strands to separate. The use of tannin alone produces hardness, though with an increase in strength. Acetate of aluminium, neutralised with sodium carbonate, gives a wrinkled product.

made from other fibrous materials, and the cleanliness of the manufacturing operations, which create little or no dust.

The spinning of yarn from finished paper was invented by Emil Claviez, who in 1895–97 took out patents for the production of yarn from paper strips and a spindle for the purpose. The manufacture of this yarn, which is known as "Xylolin," was first carried on in Saxony and subsequently in Austria. Claviez's invention has formed the basis of all the later methods of spinning paper.

The paper used for the manufacture of paper yarns may be made of any of the usual raw materials, such as chemical and mechanical wood-pulp, cotton rags, various kinds of fiber waste, and old ropes, etc. In most cases, however, the paper is made from chemical wood-pulp. Wood-pulp manufactured by the digestion of wood with caustic soda (as in the soda and sulfate methods) is regarded as superior for this purpose to that made by the sulfite process, and is said to yield a more supple and flexible paper.

"Kraft" paper is considered to be the most suitable paper for spinning, and has been found to furnish yarns 20 to 25 percent stronger than other kinds of paper. Kraft pulps are made either by the sulfate or the soda process, and the digestion is carried out under such conditions that the wood is not completely resolved into its ultimate fibers, but a certain proportion of the binding material remains. Such products are brown pulps, which do not bleach, but produce remarkable strong paper, which is very resistant to wear. Pure sulfite paper produces serviceable yarns, which for many purposes are quite satisfactory, but are not so highly valued on account of their being less elastic. For the manufacture of specially fine yarns, tissue paper gives the best results.

The paper intended for spinning is packed in wide rolls. These rolls are placed in the cutting-machine, which at one operation cuts the whole width into strips of the breadth required, usually from $\frac{1}{16}$ to $\frac{1}{2}$ in. These strips are wound on to narrow disks or bobbins, and are then twisted on spinning frames, similar to those employed in the manufacture of jute and cotton yarns. Before being twisted the strips are moistened by being led over a damping roller which dips into water (or a solution of some substance designed to increase the strength of the paper). The method of damping the strips varies, however, in different types of machinery. Jute-spinning machinery is considered more adaptable than cotton-spinning machinery for making paper yarn, the latter requiring greater modification to render it suitable for the purpose.

In the process employed by the Textilite Engineering Company of England the paper in rolls 30 ins. wide is cut by machinery into strips varying in width from $\frac{1}{16}$ to 1 in., or even more. The paper is conveyed by means of two feed-rollers to another pair of rollers, each provided with cutting disks, which are so arranged that, while cutting, they are auto-

matically sharpened. The strips are then led to two winding-on rollers, one taking even-numbered disks and the other odd-numbered disks. The disks are next transferred to a spinning machine, and are mounted on uprights over the middle of the frame, each disk being provided with a light spinning brake to prevent overrunning. As the disks contain a long length of strip, they provide practically a lasting feed to the spinning-frame. Moisture is imparted to the paper by passing the strips first over a guide-rod, extending the length of the machine, and then over a roller partly submerged in a liquid contained in a trough. The strips next pass over guide-pulleys, and are then spun or curled and wrapped on to bobbins by the ring and traveler method on the long-lift principle. Each spindle is provided with a hand-stop motion. The machines employed in subsequent operations are almost identical with those used in the jute and flax trade. The yarns, in spools of weft and warp, are subsequently transferred to the looms, in which they are woven to any desired pattern.

The yarn can be toughened by impregnation with size, tannin, aluminium formate, or sodium silicate (water-glass). It has been stated that the best method of increasing the strength of paper yarns and rendering them more resistant to moisture is to pass the yarn first through a glue, tannin, and silicate bath at 120° F., and then, without previously drying it, to pass it through a cold bath of basic aluminium formate, and afterward to dry it. The yarn when thus treated is found to have its tensile strength increased 10 percent when dry and 30 percent when wet.

The dyeing of paper textiles is effected on the same lines as cotton dyeing. Substantive, sulfur, and vat dyestuffs are employed, but greater care is required in turning and handling the materials. For this reason, the use of dyeing machines is preferable to dipping by hand; the baths must not be too strongly alkaline, and the temperature should be kept below the boiling-point, preferably at about 120° to 140° F. Either the fabric or the yarn may be dyed; but, in the case of materials to be used for clothing, it is necessary to dye the pulp before making the paper in order that the color may completely penetrate the material.

Bleaching may be effected by treating the yarn or fabric with a dilute solution of bleaching-powder, afterward transferring it to a weak acid bath, and finally rinsing well with water. In order to obtain a pure-white material, it is usually necessary to employ paper made from bleached pulp.

Paper yarns are now being used for an extremely wide range of purposes. One of the principal uses is for the manufacture of cordage, ranging from fine twine up to coarse rope. Paper string is mostly made from paper yarn alone, but in some cases the paper is spun on a central core of fine hemp twine, and in other cases on a fine metal wire. Another important use is for the manufacture of sacks and bags to replace those made from jute and hemp. The sacks are employed for various kinds of produce,

such as grain, flour, potatoes, seeds, coffee, salt, wool, artificial manures, and cement, and possess the advantage of being free from odor, and having no loose fibers on their surface which could become mixed with the contents. During the war enormous quantities of paper yarn have been used for making sandbags for army purposes. Experiments which have been made by British military authorities with captured German sandbags have shown that sandbags made entirely of paper yarn are less resistant than those of jute, and are more liable to break on impact, and that snow and frost have a deleterious effect on them. It has been found, however, that sandbags made with a jute warp and a paper weft form a satisfactory substitute for jute bags, but that the paper weft is less resistant than the jute warp.

Paper yarns are also employed for the manufacture of braiding, webbing, tent canvas, waterproof canvas, tarpaulins, mats, upholstery, and carpeting materials, wall coverings, as a foundation for linoleums and oilcloths, and for woven boards, which are said to form a suitable substitute for three-ply wood. Another use of the yarns is for the manufacture of a leather substitute, especially for machine belting. For the latter purpose the yarns are spun from parchment paper, and are afterward impregnated, wound on spools, and woven into fabrics which are stitched together to make belting of the required thickness.

Paper yarns, which have been specially impregnated, are stated to be used in the cable industry, chiefly as a partial or complete substitute for jute as a packing between the lead sheath and the iron armor of the cables. In the coating of lead-sheathed cables with waterproof composition, the winding of paper yarn is as efficient as the old jute winding, since it adheres better to the lead sheath, and blends with the composition to form a perfectly flexible and waterproof covering.

For the purposes mentioned above, the paper yarn is chiefly used in place of jute; but it is, of course, obvious that the products of its manufacture cannot possess properties equal to those of materials made from jute. Many references, however, have been made in the foreign press to the utilisation of such yarn as a substitute for cotton yarns, but it seems very doubtful if its use in this direction can be readily satisfactory except as a temporary makeshift.

21. Paper Fibers and their Examination.—Although paper is related to a rather separate industry than that of textiles, nevertheless, as shown in the preceding section, the two somewhat closely approach each other in certain particulars, so that it becomes almost impossible to entertain a detailed discussion of textile fibers without at the same time encroaching somewhat on the field of paper fibers. It is therefore considered proper at this point to introduce a brief description of these fibers together with some discussion as to their examination and determination. The fibers

which may be used in the manufacture of paper are very numerous, but are almost entirely confined to the class of vegetable materials, as may be seen by reference to the economic classification of fibers for paper given on page 331. The make-up of paper varies with its manufacture in different countries and depends on the cheapness and abundance of the fibers which are most available commercially. In this country the various wood-pulps (mechanical, sulfite, and soda pulps) are the chief basis for paper making, although many other fibers, such as cotton (from rags, cotton waste, and linters), linen (from rags and flax waste), hemp and jute (from old fabrics and tow waste), Manila hemp (from old cordage and tow), and many other miscellaneous vegetable fibers are extensively used, sometimes alone, but more often in admixture in varying proportions with wood-pulps. The fibers used in other countries, however, are much more extensive; besides those already enumerated we find grass fibers like esparto; straw fibers such as those from corn, wheat, and rice; as well as fibers from the bamboo, mulberry tree, linden tree, and the hop vine and sugar cane.

Fig. 360.—Ground Wood-pulp from Aspen. (Herzog.)

In the examination of paper fibers it is first necessary to isolate the individual fibers from the paper web and the sizing and loading materials. This may usually be done by tearing up the sample of paper into small pieces and then boiling with water and beating up with a vigorous stirring (as with an egg beater) until a fine pulp is produced. This is washed and strained off on a fine copper gauge, after which the fibers may usually be rather easily picked apart for examination.

It must be borne in mind that the fibers in paper have undergone a rather severe chemical and mechanical treatment during the processes of manufacture into paper, consequently they will exhibit characteristics rather different from those of the natural fibers. These operations include, as a rule, a prolonged boiling under high pressure with caustic alkalies or calcium bisulfite, and also a treatment with comparatively strong solutions of bleaching powder. In paper-making it is also necessary to have short,

fine fibers rather than the comparatively long and sometimes much coarser fibers employed for spinning textiles.

The following is a brief description of the more important paper fibers:

(1) **Mechanical Wood Fiber.**—This is prepared by grinding up wood so that it becomes disintegrated into the short ultimate fibers. For this purpose the white soft woods (like poplar) are largely used; also many coniferæ woods (like pine, fir and spruce) as well as some leafed trees (like the aspen, linden and willow). Mechanical wood fiber contains practically all of the natural elements present in the wood, and conse-

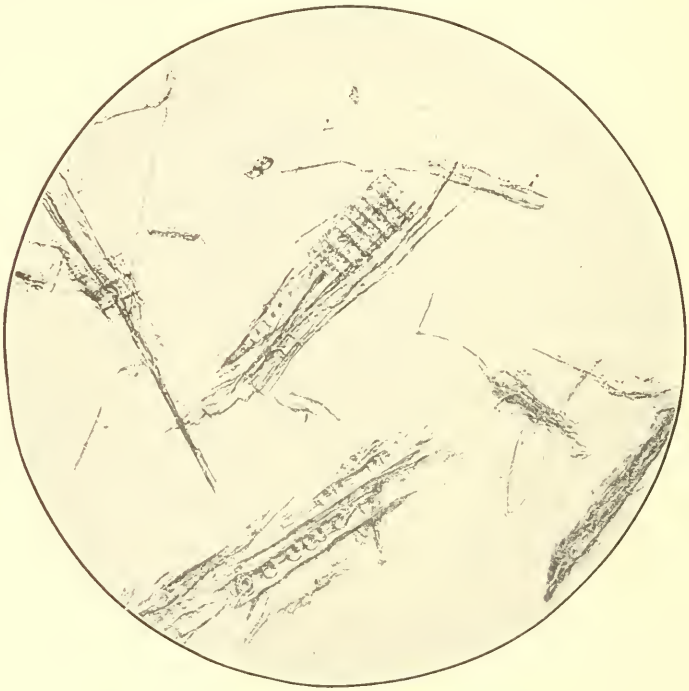


Fig. 361.—Ground Wood-pulp from Fir. (Herzog.

quently is very easy to recognise and identify both by microscopic examination and by microchemical tests. According to Höhnel, the coniferous varieties of wood fiber are characterised by their tracheides covered with large circular disks. These are mostly flat, and usually torn and frayed more or less by the process of grinding, and have blunt wide ends, and are furthermore relatively thin walled.

The wood fiber from leaf trees lacks these characteristic tracheides, but possesses instead numerous remnants of vascular tissue, which are short and broad. These are covered quite thickly with small flattened disks which mutually touch each other. There are also present thin

fibers which (in the so-called white woods) are generally only slightly thickened.

When it is a question of distinguishing between the varieties of coniferæ which occur in a paper, then the tracheides no longer suffice, as these are nearly the same for all such trees. On the other hand, the marrow-lined cells which occur in large number in all wood-pulps, in the case of the coniferæ possess very different characteristics. Herewith is given only the most important points which may serve for an examination of the fibers, as well as the characteristics shown in Fig. 360. The marrow cells appear in wood-pulp usually as brick-shaped cells connected in a parallel manner. If all of these cells are provided with single round pores, then it indicates pulp of spruce wood. If there occurs besides these single-pored marrow cells others which show small breeched spots,

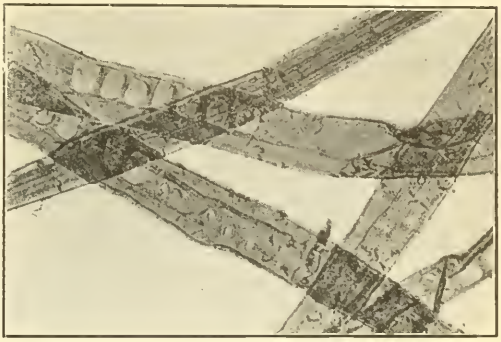


Fig. 362.—Wood-pulp from Fir. (Herzog.)

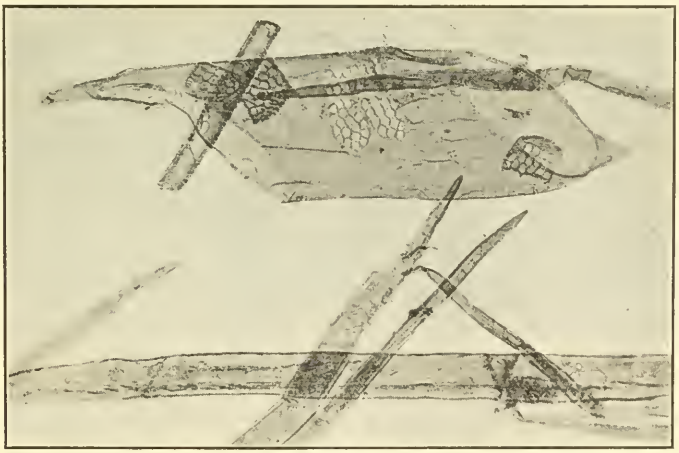


Fig. 363.—Wood-pulp Fibers from Willow. (Herzog.)

then we have pine wood-pulp (Fig. 361). Finally, if a portion of the marrow cells are provided with large, and very noticeable teeth which project far into the lumen (in which occur small circular spots) while the rest show a series of large, rounded, quadrangular perforations which take up almost the entire width of the lumen, then the paper consists of fir wood (Fig. 362).

With respect to the examination of the principal leafed woods, only the most essential will be given. The wood-pulp elements of willow (Fig. 363), poplar (Fig. 364) and linden trees are very thin-walled, while those of maple are thick-walled. The woody material of the linden shows remnants of vascular tissue and tracheides, which besides exhibiting disks, also shows a broad spiral band. The former are up to 60 microns wide. Maple pulp also shows numerous remnants of

Fig. 364.—Wood-pulp from Poplar. (Herzog.)

vascular tissue which are spotted and spirally thickened, though generally only one of these marks is present. Willow and poplar have fibers very much alike, being associated with vascular tissue which is completely covered with hexagonal disk-like spots.

Paper or paper pulp containing mechanical wood-pulp always shows the woody fiber reactions in the most distinct manner. Aniline sulfate, for example, gives an intense golden-yellow color. Further it is to be remarked that only pasteboard, but not paper, as a rule, is made entirely from mechanical wood-pulp. Therefore, in the case of papers which

show the woody fiber reaction, one must also look for other fibers after the application of the woody fiber reaction.

(2) **Chemical Wood Fiber.**—This includes three principal varieties, depending on the method of manufacture: (*a*) *sulfite pulp,* made by boiling chipped wood under high pressure (90 to 150 lbs.) with calcium bisulfite; (*b*) *soda pulp,* made by a similar boiling with caustic soda liquor; (*c*) *sulfate pulp,* made by boiling with a mixture of caustic soda and sodium sulfide. When wood is decomposed into its elements by chemical methods the product so obtained is rather pure cellulose; so

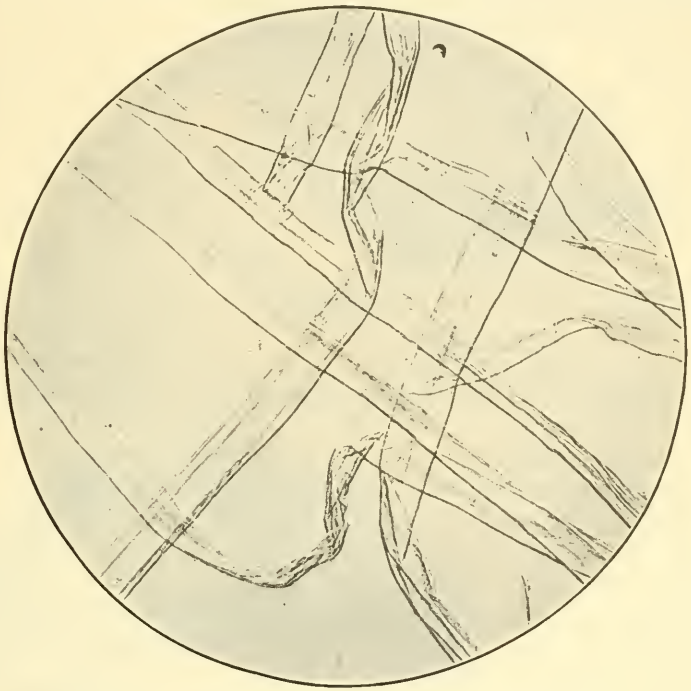


Fig. 365.—Chemical Wood-pulp from Fir. (Herzog.)

that whereas ground wood-pulp shows the lignin reactions in a very distinct manner, paper containing chemical pulp does so either not at all or only in a slight degree. By the boiling, however, with chemicals not only is the lignin destroyed, but the nature of the woody elements is also changed, so that chemical cellulose cannot be recognised under the microscope as easily as ground wood. Chemical pulp is chiefly prepared from the long-fibered varieties of coniferous trees. The fibers appear broad, ribbon-like, often twisted, and resemble cotton (being broader), however); thin-walled; occasionally there may be seen large spots surrounded by a halo, although always indistinct (Fig. 365). The best way

to see them is to treat the fiber with chlor-iodide of zinc, when most of them become violet, others acquire a dirty violet to yellow color, and the marks of the large spots stand out distinctly. The fibers are 30 to 60 microns wide, and show no joints. They are also almost entirely whole, whereas those of mechanical pulp are much broken and torn apart. The ends are generally broad, thin-walled and blunt. Marrow elements are only occasionally observed, and exhibit only indistinct structural proportions. From these remarks it is evident that mechanical and chemical wood pulps may be distinguished from each other very easily.

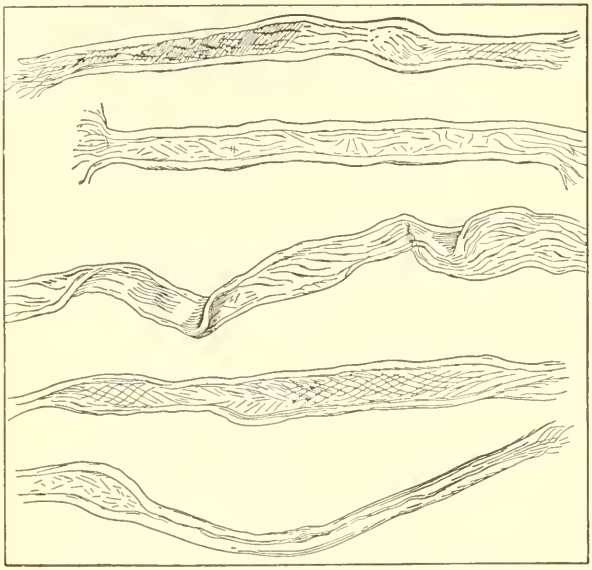


Fig. 366.—Cotton Fibers from Paper. (Litschauer.)

(3) **Cotton.**—This fiber as found as a constituent of paper exhibits about the same characteristic appearance as already described under its consideration as a textile fiber. The chief difference to be noted is that the fiber is generally torn (Fig. 366) and not nearly so well preserved. It is easy to recognise cotton in paper by its well-defined walls, its characteristic twist (though care must sometimes be exercised not to confuse this with that of some wood fibers), and its cuticle. The cell-wall is frequently broken down, but never shows the knotted swellings to be noticed on linen and hemp.

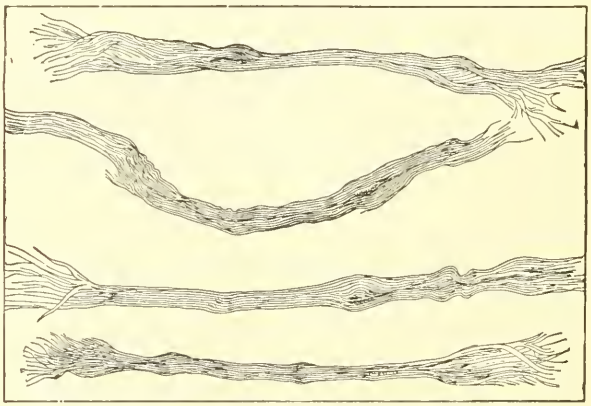


Fig. 367.—Linen Fibers from Paper. (Litschauer.)

(4) Linen.—It would be erroneous to expect to find linen fibers in paper in the same condition as that in which they occur in fabrics. As a rule the linen fibers employed in paper are derived from flax tow and rags almost without exception. In old linen rags the fibers are already much broken up and spilt and more or less destroyed; still more is this the case in paper, especially in the more delicate kinds. The knotted swellings on the linen fiber are characteristic, and they occur around the joints. Longitudinal rents and fissures are so frequent, that the lumen is scarcely recognisable; and at the ends the linen fibers in paper are often completely frayed out into fine fibrillæ (Fig. 367).

Fig. 368.—Hemp Fiber from Paper-pulp, Much Decomposed. (Herzog.)

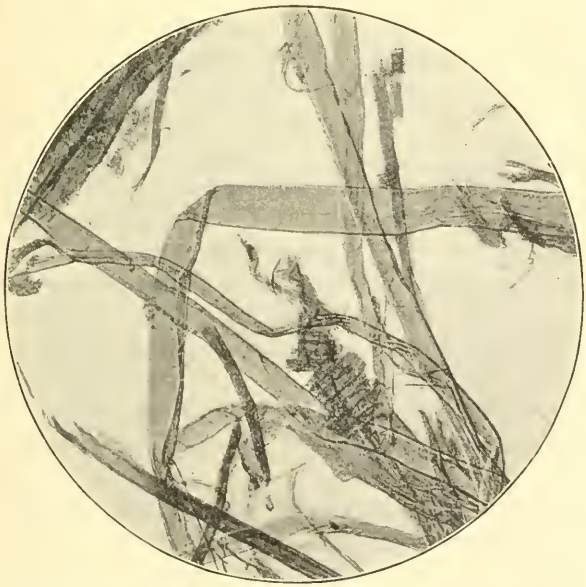


Fig. 369.—Paper-pulp; Mixture of Ground Wood, Sulfite Pulp and Cotton. (Herzog.)

(5) Hemp Fiber.—These fibers occur in most papers in a well-preserved condition. Such papers are made from hemp tow, like banknote paper, etc., and have great endurance and strength even in thin tissues. Paper prepared from old hemp rags show broken-up fibers in the same manner as linen paper. Since hemp fibers, however, are more brittle, the torn

ends appear somewhat shorter than with linen. There are also always a smaller number of destroyed fibers, which is of use in determining hemp fibers in paper with certainty (Fig. 368).

(6) **Straw Fibers.**—These are obtained from wheat, rye, oats, rice, and corn, and are always easy to recognise in paper, since besides the usual characteristics of fibers there occur in them elements which are especially easy to recognise. These are bundles of thin spiral and reticulated vascular tissue or fragments of such (portions of spiral-shaped ridges, single rings, etc.). Furthermore there are present large, loose parenchymous cells, generally wide, thin-walled, short, with blunt angles, or long; in the last case up to 33 microns broad and often porous. Thirdly, there are very thick, silicified epidermal cells. These possess highly characteristic forms and serve for the recognition of straw in paper with great certainty. They are flat, possess thickened outer walls and thin inner walls. The side walls exhibit numerous regular curves or undulations, so that the long, narrow epidermal cells appear like double-edged saws (Figs. 370, 371). The fibers of the first four varieties of straw named are incidentally as broad as linen fibers, but also shorter. They are not lignified and are relatively thinner-walled than linen fibers. The ends are almost always pointed or forked. The numerous joints are also remarkable; these, however, were not present originally, but are a result of the preparation of the straw. Furthermore, straw fibers are very unequal in thickness; next to very thin ones may be found very thick and short ones. An important difference between straw and linen fibers lies in their condition of preservation. Straw fibers in paper are always well known for having all their peculiarities—namely, their pointed and frequently forked ends which are often to be seen, whereas linen fibers occur almost altogether in the form of fragments, which even then are usually more or less decomposed. According to Wiesner the mean diameters of straw fibers are as follows: barley, 5 to 12 microns; oats, 10 to 21 microns; rye, 9 to 17 microns; wheat, 10 to 21 microns; fibers of corn can be distinguished from the usual straw fibers by their large diameters (10 to 82 microns) and by

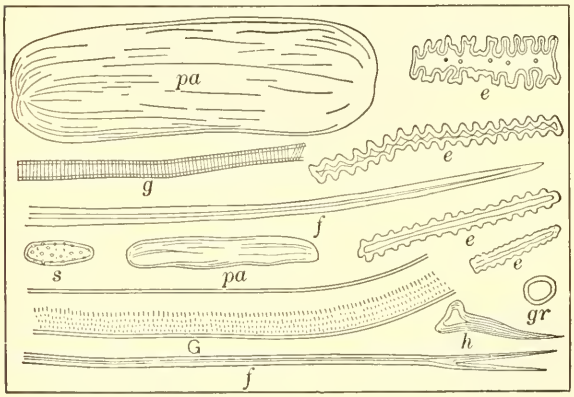


Fig. 370.—General Appearance of Straw Fibers from Paper. (Höhnel.)

their form. They usually have blunt, forked, knotty ends, which often appear almost like antlers. Their length amounts to 0.4 to 5.6 mm., and is almost distinguishing. The fibers, as a rule, are relatively thin-walled, and the lumen appears only very seldom as a narrow line. They contain, according to Wiesner, a steel-gray tannin matter, and unlike fibers of oats, barley, rice, wheat, and rye, are lignified. Corn paper (Fig. 371) can consequently be distinguished from ordinary straw paper and from true rice paper by the fibers. The various straw papers, however, can only be distinguished from each other with certainty by the aid of the epidermal cells, and even by the form as well as by the dimensions of these cells. According to Wiesner, these epidermal cells have the following dimensions:

	Length in Microns.	Breadth in Microns.
Corn straw	108–252	36–90
Rye straw	86–345	16–10
Esparto straw	28– 88	7–19
Barley straw	103–224	12–14
Wheat straw	152–449	18–24
Oat straw	186–448	12–17

As to differences in form, it may be said that oat, rye, and wheat straw have right-angled epidermal cells. The side walls, in the case of rye straw, are very wavy, with wheat straw almost straight, and with oat straw slightly wavy. The epidermal cells of barley straw appear more irregular and almost rhombohedral in form. In paper from corn straw there occur epidermal cells which are very irregular and broad and rough-walled; they often occur in large groups, which are as much as 1 sq. mm. in size. Rice straw (Fig. 372) possesses very narrow fibers (mostly 7 microns broad) and narrow, relatively long epidermal cells, with remarkably thick external walls, which exhibit wart-like swellings. The Chinese rice papers (mostly wall-papers) are usually sized with a thick paste, and also contain many parenchym cells, which give additional strength (Höhnel).

(7) **Jute Fiber.**—The characteristics of this fiber in paper are practically the same as those already given under its consideration as a textile fiber.

(8) **Esparto Fiber.**—This fiber is obtained from a grass, *stipa tenacissima*, and is extensively used for paper-making in Europe. In its microscopic characteristics it belongs to the general category of straw fibers. Höhnel states that it is distinguished by its peculiar epidermal cells (Fig. 373).

(9) Bamboo Fiber.—This is worked up into paper in China, Japan, Jamaica, England, and other countries. The fine paper known by the name of Chinese silk paper is usually made from bamboo, partly from old bamboo cane, and partly from the young shoots. According to Wiesner, bamboo paper exhibits bast fibers differing much in form but which can be included in the following three forms: (1) Short (mean length, 720 microns), narrow fibers, having a line-shaped lumen. (2) Long, wide, somewhat thickened to 17 microns in diameter. (3) Long, ribbon-shaped flat fibers, of very changing breadth, which are twisted somewhat after the manner of cotton. Of course there will also be found in bamboo paper occasional masses of vascular tissue (mesh, porous, as well as ring and spiral forms). Often single rings can be observed in the paper.

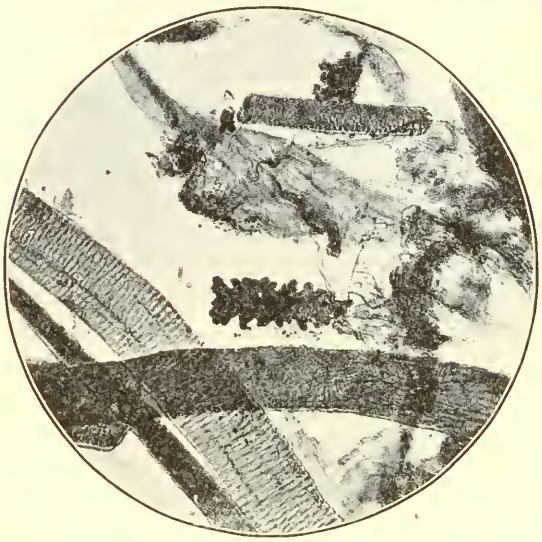


FIG. 371.—Straw Paper-pulp Showing Siliceous Cells. (Herzog.)

(10) Paper Mulberry Fiber.—The soft bast fiber of the paper mulberry tree is extensively employed in Japan and China for the making of a quality of paper especially characteristic of these countries. This fiber may be distinguished by the thin, curly, white coat of cellulose with which it is surrounded; also the short, bar-like or prismatic crystals, which occasionally adhere to the fibers in the

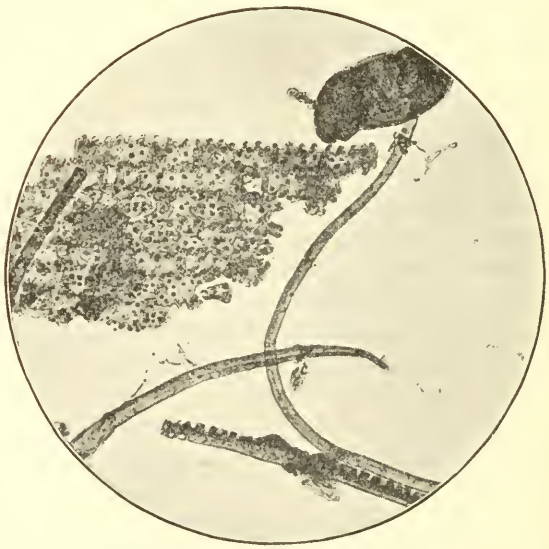


FIG. 372.—Chinese Rice Straw Paper.

paper (Fig. 374). The fiber of the paper mulberry tree is the longest employed in paper-making. Hence the tenacity of the Japanese and Chinese papers prepared from this material. Hence also the possibility of preparing from this fiber a paper which is mesh-like, transparent and soft on the surface.

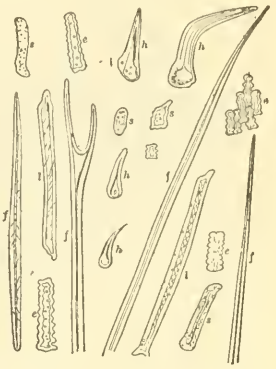


Fig. 373.—Fibers of Esparto Grass. *s*, Short sclerenchymous elements; *l*, cells; *f*, fibers; *h*, hairs; *e*, epidermal cells. (Höhnel.)

(11) Hop Fiber.—This is principally used in fine papers. In such, however, the single fibers are so much decomposed, that they are determined only with difficulty.

(12) Papers with Cellular Structure.—The so-called Chinese rice paper and the papyrus of the ancients, are papers which differ completely in their microscopical properties from those hitherto considered. They consist principally of thin-walled, free parenchymous cells, and are obtained by cutting out with a knife the pith of certain monocotyledonous soft stems.

(*A*) *Chinese paper* (so-called rice paper) is prepared in a simple manner by cutting out in a spiral form the pith of *Aralia papyrifera* (Fig. 375). The sheets so obtained are then pressed and attain a size of about 11 sq. dcm. Each sheet consists only of a single piece of 250 to 300 microns in thickness. Only smaller and more imperfect kinds appear in joined strips 1 to 2 cm. wide. These are cut out of the pith in radial directions. The microscope shows polyhedral parenchymous cells, which are completely filled with air that can easily be displaced with alcohol. The cells are striated lengthwise, and measure 135 to 180 microns in length and 54 to 92 microns in breadth. The cells are provided with small pores, and many contain crystal husks of calcium oxalate.

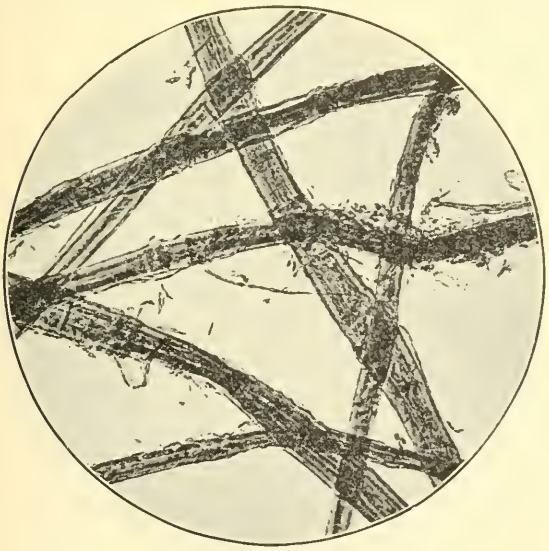


Fig. 374.—Fiber from Paper Mulberry. (Herzog.)

(*B*) *Papyrus* of the ancients was cut from the fabric of the stalk of the *Cyperus papyrus* (Fig. 376). This fabric consists of a curly, almost snow-white parenchym similar to elder pith, in which numerous vascular bundles are imbedded. The papyrus rolls are so prepared that the pith is cut up in very thin sheets, and these are generally glued together in three layers not parallel, but crossing one another. Hence the old papyræ show two systems of striations at right angles to each other; which are caused by the vascular bundles (Höhnel). The sheets of pith are about 80 microns in thickness according to Wiesner. The parenchymous cells are large and thin-walled, and nearly always contain small crystals of calcium oxalate. The vascular bundles are well preserved even in antique samples, and allow of their histological structure to be recognised very distinctly under the microscope.

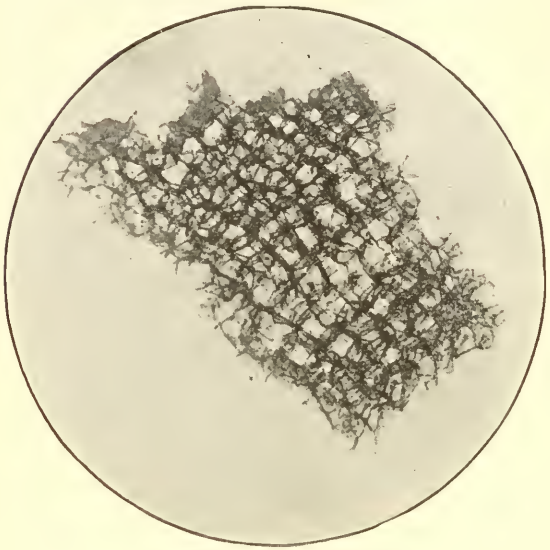


Fig. 375.—Chinese Rice Paper.

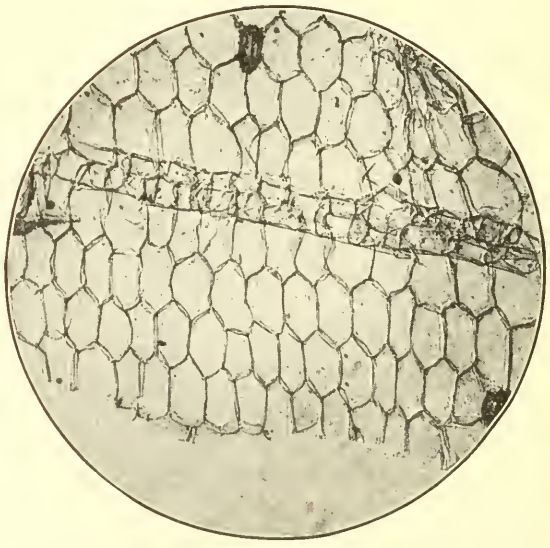


Fig. 376.—Ancient Papyrus.

With regard to the chemical reactions that can be used in the large-scale examination of paper for its fibers, only those pertaining to woody fiber are useful (aniline sulfate, phloroglucinol and hydrochloric acid, or indol and

hydrochloric acid). By these reactions, however, a definite fiber is seldom distinguished; but only the presence of more or less lignified matter is recognised. Hence, by the use of the woody fiber reactions the presence of lignified fibers in the mass of the paper only is indicated; the quantity present and the kind of lignified fiber is not shown. We must also bear in mind with regard to the species of fiber, that these may often be lignified or not according to the method of their preparation, as by certain chemical means (alkalies, acids, bleaching materials) the woody fiber can be destroyed. When two or more fibers are mixed together, the determination of the relative amounts of each present can only be effected by the use of the microscope, and indeed only by an accurate counting of the different kinds of fibers found.

CHAPTER XXV

GENERAL ANALYSIS OF THE TEXTILE FIBERS

1. General Classification.—In a commercial examination of most manufactured yarns, fabrics, etc., it will only be necessary to distinguish between wool, silk, cotton, linen, jute, hemp, and ramie. Under wool must also be included analogous animal hairs, such as mohair, cashmere, etc. Other animal fibers, such as cow-hair and horse-hair, may easily be distinguished even by the naked eye. Of course there are numerous other fibers of vegetable origin which are employed more or less for textile materials, but either they are not liable to occur in conjunction with the above fibers, or they may be readily distinguished from the latter without requiring a special examination.

Dodge gives a list of American commercial vegetable fibers, the total number of which is about 30, of which the more important are as follows:

Six bast fibers:

- Flax, *Linum usitatissimum.*
- China grass, *Bahmeria nivea* and *B. tenacissima.*
- Hemp, *Cannabis sativa.*
- Jute, *Corchorus capsularis* and *C. olitorius.*
- Sunn hemp, *Crotalaria juncea.*
- Cuba bast, *Hibiscus tiliaceus.*

The first five of this class are used for spinning fibers, while the latter finds use for millinery purposes.

Two surface fibers:

- Cotton, *Gossypium* sp.
- Raphia, *Raphia ruffia.*

Fifteen structural fibers, representing agaves, palms, and grasses:

- Sisal hemp, *Agave rigida* } Cordage fibers.
- Manila hemp, *Musa textilis* } Cordage fibers.
- Mauritius hemp, *Fourcroya gigantea* } Cordage fibers.
- New Zealand flax, *Phormium tenax* } Cordage fibers.
- Tampico or Istle, *Agave heteracantha* } Brush fibers.
- Bahia piassave, *Attalea funifera* } Brush fibers.
- Para piassave, *Leopoldinia piassaba* } Brush fibers.
- Mexican whisk or Broom root, *Epicampes macroura* } Brush fibers.
- Cabbage palmetto, *Sabal palmetto* } Brush fibers.
- Crin végétal, *Chamærops humilis* } Upholstery and matting fibers.
- Spanish moss, *Tillandsia usneoides* } Upholstery and matting fibers.
- Saw palmetto, *Serenoa serrulata* } Upholstery and matting fibers.
- Cocoanut fiber, *Cocos nucifera* } Upholstery and matting fibers.
- Esparto grass, *Stipa tenacissima*, a paper fiber.
- Vegetable sponge, *Luffa ægyptica*, a substitute for sponge.

The native vegetable fibers of the United States that are produced in commercial quantities are cotton, hemp, flax, palmetto fiber, and vegetable hair from Spanish moss.

2. Microscopical Investigation.—The best method of distinguishing qualitatively between the various fibers above mentioned is by the use of the microscope, whereby their characteristic physical appearance may be readily observed. Each of the fibers in question presents certain microscopical peculiarities, so that no difficulty is encountered in distinguishing between them. The difference in the microscopical appearance of these fibers may be comparatively observed by reference to the figures given in the preceding pages.

In advising as to the methodical examination of fibers, Höhnel states that a commercial fiber should first be described as completely as possible by the field of its use if it is desired to know all of its distinguishing marks. In such a case it is possible to arrive at a position where an analytical table may be prepared capable of being used for the determination of the fiber as well as of the plant. Höhnel deviates in this connection from the not unusual point of view that to be able to fix accurately the identity of a fiber it is only necessary to furnish a complete description of its physiography. He is opposed to the opinion that a mere description is all that is necessary, because by this means it is not always possible to differentiate between such a fiber and the one immediately next to it in properties. In fact, up to now it has been customary to regard practical microscopy more as a descriptive science than as a comparative one, and thus to attribute to the easily recognisable characteristics too great an analytical accuracy. The recognition of fibers lies much deeper, and must be established by a labor implying deep insight and often much toil, and must often be sought for in quite unessential peculiarities of very slight anatomical importance.

The principal characteristics should always be morphological, that is to say, those which define the form of the fiber (base, lumen, relative thickness of cell-walls, points, condensed forms, etc.). The other characteristics, namely, the comparative size and the chemical properties of the fiber, should only be considered of secondary importance. The size of the fibers often varies in an unexpected manner, especially in plant fibers where the difference is a physiological one. The longer, for instance, a sample of linen, jute, etc., may be in consequence of favorable external conditions, the longer will also be the fibers contained in the same.

As far as the microchemical relations are concerned, heed must be taken of the fact that in the literature of the subject attention is seldom paid to the concentration of the reagents employed, and further it must be borne in mind that in dealing with fabrics containing artificially dyed

fibers, chemical color reactions in general cannot be applied. Iodine and sulfuric acid, for instance, depending on the concentration, give with cotton all colors from a bright rose to a dark blue, with hemp from yellow to greenish blue, etc. Again, fibers may be so changed by bleaching that the microchemical reactions as described do not hold true. Woody matter can be completely dissolved out by the bleaching process, and the cuticule be destroyed. The behavior of cotton towards copper ammonium oxide solution will not hold for well-bleached cotton yarn, because in such the cuticule is almost entirely lacking. The statements concerning the chief chemical distinctions between linen, hemp, and jute fibers are useless when one is dealing with well-bleached or dyed materials.

Consequently, in the testing and investigation of fibers the morphological properties should be given precedence, as only these exhibit well-defined characteristics. In order to be thoroughly certain when testing by microchemical properties, it is necessary always to employ the same reagents. Every characteristic of a fiber has only a relative value, because it is only serviceable in distinguishing the fiber in question from one or more particular fibers, while with others it would be worthless. Thus it is easy to distinguish between jute and hemp by the so-called "knots" or folds of flexion, but this characteristic will not enable one to distinguish between hemp and flax.

3. Qualitative Chemical and Microchemical Tests.—A rough physical test to distinguish between animal and vegetable fibers is to burn them in a flame. *Vegetable* fibers burn very readily and without producing any disagreeable odor; *animal* fibers, on the other hand, burn with some difficulty and emit a disagreeable empyreumatic odor resembling that of burning feathers. The burnt end of the fiber is also characteristic, vegetable fibers burning off sharply at the end, whereas animal fibers fuse to a rounded, bead-like end.

Tables I and II exhibit the characteristic chemical reactions of the principal fibers, and by suitably employing these tests the principal fibers may be easily distinguished from one another.

4. Reagents for Testing Fibers.—The reagents employed for the tests in the tables may be prepared as follows:

(1) *Madder Tincture.*—Extract 1 gram of ground madder with 50 cc. of alcohol, and filter from undissolved matter. Used for distinguishing between cotton (bright yellow) and linen (orange.)

(2) *Cochineal Tincture.*—This is made in the same manner as the above, using 1 gram of ground cochineal insects. Used for distinguishing between cotton (red) and linen (violet).

(3) *Fuchsine Solution.*—Also known as Liebermann's test solution. Dissolve 1 gram of Fuchsine (Magenta) in 100 cc. of water, then add caustic soda solution, drop by drop until the fuchsine solution is decolorised; filter and preserve in a well-stoppered bottle. In applying the test with this reagent, the mixed fibers are treated with the

hot solution, then well rinsed, when the animal fibers will be dyed red, the vegetable fibers remaining colorless.

(4) *Zinc Chloride Solution.*—Dissolve 1000 grams of zinc chloride in 850 cc. of water, and add 40 grams of zinc oxide, heating until complete solution is effected.

(5) *Stannic Chloride Solution.*—This may be prepared by dissolving 15 grams of stannous chloride ($SnCl_2$) in 15 cc. of concentrated hydrochloric acid, and then gradually adding 3 grams of powdered potassium chlorate ($KClO_3$). Dilute to 100 cc. with water.

(6) *Silver Nitrate Solution.*—5 grams of silver nitrate ($AgNO_3$) are dissolved in 100 cc. of water, and preserved in an amber-colored bottle.

(7) *Mercury Nitrate, Millon's Reagent.*—Dissolve 10 grams of mercury in 25 cc. of nitric acid diluted with 25 cc. of water at a lukewarm temperature. Mix this solution with one of 10 grams of mercury in 20 cc. of fuming nitric acid. Used for testing presence of animal fibers (red). Solution is not very stable.

TABLE I

Test.	Wool.	Silk.	Linen.	Cotton.
DYESTUFF TESTS				
Madder tincture	Nil	Nil	Orange	Yellow
Cochineal tincture	Scarlet	Scarlet	Violet	Light red
Fuchsine	Red	Red	Nil	Nil
Acid dyes in general	Dyed	Dyed	Nil	Nil
Mikado yellow	Nil	Nil	Dyed	Dyed
ACTION OF VARIOUS SALTS				
Zinc chloride	Partly diss.	Dissolves	Fiber undiss., yellow color	
Stannic chloride	Nil	Nil	Black color	
Silver nitrate	Violet to brown	Nil	Nil	
Mercury nitrate (Millon's)	Red to brown	Nil	Nil	
Cupric or ferric sulfate	Black	Nil	Nil	
Sodium plumbite	Black ppt.	No. ppt.	Nil	
Ammoniacal copper oxide	Swells only	Nil	Swells and partly dissolves	
Ammoniacal nickel oxide	Undissolved	Dissolves	Undissolved	

(8) *Copper Sulfate or Ferric Sulfate.*—Dissolve 5 grams of these salts respectively in 100 cc. of water.

(9) *Sodium Plumbite.*—Dissolve 5 grams of caustic soda in 100 cc. of water and add 5 grams of litharge (PbO), and boil until dissolved. Used to detect the presence of wool or hair fibers.

(10) *Ammoniacal Copper Oxide, Schweitzer's Reagent.*—Dissolve 5 grams of copper sulfate in 100 cc. of boiling water, add caustic soda solution till the copper compound is completely precipitated, wash the precipitate of copper hydrate well, then dissolve in the least quantity of ammonia water. This gives a deep blue solution. All solutions of ammoniacal copper oxide do not cause cotton to swell up very much and dissolve. The solution must be concentrated and be freshly prepared. The best working reagent is prepared by washing freshly precipitated copper hydrate, then pressing between filter paper to remove excess of liquid, and dissolving in the

TABLE II

Test.	Wool.	Silk.	Linen.	Cotton.	Hemp.	Jute.
Caustic potash	Dissolves	Dissolves	Swells up and becomes brown	Swells up and becomes yellowish	Colored brown	
Caustic soda	Dissolves gradually	Dissolves gradually and becomes reddish	Brown yellow	Faintly yellow	Brownish	
Ammonia	—	—	—	—	Unretted, yellow; retted violet	—
The alkali solution of the fiber treated with:						
Sodium nitroprusside	Violet	Nil	—	—	—	—
Lead acetate	Black	Nil	—	—	—	—
Copper sulfate	Violet then brown	Violet	—	—	—	—
Sulfuric acid	Does not dissolve till heated	Dissolves quickly in hot	Dissolves quickly in cold	Dissolves quickly	Dissolves slowly	Dissolves slowly
Nitric acid	Yellow, dissolves slowly	Yellow, dissolves quickly	Dissolves without color	No color	Yellow color	—
Chlorine water	Yellow	Yellow	Bleaches	Bleaches	Yellow-brown	Violet on addition of ammonia
Iodine solution	—	—	Yellow	Yellow	—	Light brown
Picric acid	Yellow	Yellow	Nil	Nil	Nil	Nil
Iodine and sulfuric acid	—	—	Swells, blue	Swells, blue	Swells, green	Swells, yellow to brown
Thymol and sulfuric acid	—	—	Violet	Violet	—	—
Sugar and sulfuric acid	Rose red	Rose red	—	—	—	—

least possible amount of concentrated ammonia. This reagent should be preserved in a tightly stoppered bottle and away from the light. The bast fibers of flax and hemp are not completely soluble in this reagent. They are merely swollen strongly, and then often present forms which closely resemble those assumed by cotton. If the ammoniacal copper oxide solution is not sufficiently concentrated the globular swellings do not occur, and the fiber only swells up uniformly.

Böttcher recommends that the solution be prepared as follows: A glass tube about 2 ins. in diameter and 24 ins. in length is loosely filled with thin sheet copper and and then filled up with ammonia water. After a few minutes, the liquid is drawn off, and then poured over the copper again. This process is repeated during several hours, when a deep blue saturated solution of ammoniacal copper oxide is obtained. Neubauer recommends to precipitate a solution of copper sulfate with caustic soda in the presence of ammonium chloride; the precipitate so obtained is washed several times by decantation and finally on a filter. It is then dissolved in the least quantity of ammonia water. Wiesner prepares the solution by digesting copper turnings with ammonia water in an open flask.

(11) *Ammoniacal Nickel Oxide.*—Dissolve 5 grams of nickel sulfate in 100 cc. of water and add a solution of caustic soda until the nickel hydrate is completely precipitated; wash the precipitate well and dissolve in 25 cc. of concentrated ammonia and 25 cc. of water. This solution dissolves silk almost immediately, but reduces the weight of vegetable fibers only about $\frac{1}{2}$ percent, and of wool only $\frac{1}{3}$ percent.

(12) *Caustic Potash or Caustic Soda.*—Dissolve 10 grams of the caustic alkali in 100 cc. of water.

(13) *Sodium Nitroprusside.*—Dissolve 2 grams of the salt in 100 cc. of water.

(14) *Lead Acetate.*—Dissolve 5 grams of lead acetate crystals (sugar of lead) in 100 cc. of water.

(15) *Sulfuric and Nitric Acids.*—The commercial concentrated acids are employed.

(16) *Chlorine Water.*—Water is saturated with chlorine gas obtained by acting on pyrolusite (MnO_2) with hydrochloric acid. The solution should be preserved in amber-colored bottles.

(17) *Iodine Solution.*—Dissolve 3 grams of potassium iodide in 60 cc. of water, and add 1 gram of iodine. Dilute this solution, before using, with 10 parts of water. When the reaction is employed in connection with sulfuric acid, the latter consists of 3 parts of concentrated sulfuric acid, 1 part of water, and 3 parts of glycerol. The glycerol has the effect of preventing injury to the fibers, and at the same time brings out certain details of the structure when the fibers have previously absorbed the iodine. The fibers are moistened first with the iodine solution and then with the sulfuric acid solution. According to Höhnel, the iodine solution is prepared as follows: One gram of potassium iodide is dissolved in 100 cc. of distilled water, and then iodine is added until the solution is saturated. In order to maintain this solution in a constantly saturated state, an excess of iodine is added, which remains at the bottom of the bottle. The sulfuric acid solution consists of 2 parts by volume of pure glycerol, 1 part by volume of distilled water, and 3 parts of ordinary concentrated sulfuric acid. These must be mixed gradually and carefully, keeping the flask well cooled. Both of these solutions in time change their constitution and concentration. The iodine solution must be renewed, while the sulfuric acid solution may be made good after long standing by the addition of some concentrated acid. The working qualities of both these solutions may be tested by allowing them to act on some raw flax fibers. These should not swell up on treatment with the sulfuric acid (hence exhibit no change in form) and should appear pure blue. If the fibers swell up, the sulfuric acid is too concentrated; if the blue color is not immediately developed (only appears of a violet

or rose color), the sulfuric acid is too dilute. In the first case more glycerol must be added, and in the latter more concentrated acid must be added.

The reliability of this latter test depends very largely on the method of manipulation. The most important detail is probably the concentration of the acid used. After the fibers have been moistened with the iodine solution excess of the latter should be removed by pressing between blotting paper, so that only that portion of the solution absorbed by the fibers remains. This is important, for if the iodine solution remains between the fibers the test will be indecisive. It is also important that the individual fibers be separated from each other so that the reagents may act uniformly. If the acid is too concentrated most of the fibers assume a blue color, swell up and finally dissolve; whereas if the acid is too weak, all the fibers exhibit a reddish coloration. In carrying out the test, the fibers should first be boiled with potash, washed, spread out on glass slides, dried, then treated with the ruby red solution of iodine, again dried, and finally mounted in the sulfuric acid solution.

(18) *Picric Acid Solution.*—Dissolve 0.5 gram of picric acid in 100 cc. of water.

(19) *Chlor-iodide of Zinc.*—Dissolve 1 gram of iodine and 5 grams of potassium iodide in 14 cc. of water, then add 30 grams of a concentrated solution of zinc chloride (Höhnel). This reagent is important for bringing out the structural parts of vegetable fibers.

(20) *Alcohol.*—The usual 95 percent commercial quality; employed as a useful reagent for removing fatty matters from the fibers and also for preparing solutions of various colored stains.

(21) *Ammonia.*—Strong water of ammonia; useful for removing coloring matters from dyed fibers previous to examination.

(22) *Aniline Sulfate.*—The concentrated aqueous solution slightly acidulated with sulfuric acid. A good reagent for detecting lignified tissue (yellow color).

(23) *Benzoazurine.*—Used in a hot solution made slightly alkaline with soda ash; gives a violet color on hemp and flax and both fibers show strong dichroic colors.

(24) *Benzopurpurine* 10B in combination with Malachite Green. This is Behren's reagent to distinguish between flax and hemp.

(25) *Carbolic-Fuchsine.*—This is known as Muller's reagent for staining lignified cell tissues. Dissolve 1 gram of Fuchsine in 10 cc. of alcohol and then add to 100 cc. of water in which 5 grams of crystallised carbolic acid have been previously dissolved.

(26) *Chloral Hydrate.*—Useful for bringing out the structure of vegetable fibers, though seldom used; dissolve 5 grams of chloral hydrate in 2 cc. of water.

(27) *Chromic Acid.*—Used for isolating the elements of vegetable fibers. The solution is prepared according to Wiesner by mixing potassium bichromate with an excess of sulfuric acid. From the resulting solution the chromic acid separates out and is then dissolved in an equal quantity of water. It may be used in the cold solution and destroys the cellulose less than Schulze's macerating solution.

(28) *Chrysophenine in Combination with Safranine.*—Used by Behrens to distinguish between flax and cotton.

(29) *Dimethyl-paraphenylene-diamine.*—This is employed by Wurster for the detection of lignin (carmine color). It is conveniently used as the sulfate, a small granule being dissolved in a few drops of water.

(30) *Diphenylamine.*—Its solution in concentrated sulfuric acid is employed as a test for collodion silk (blue color). The other cellulose silks, gelatine silk and natural silks remain unchanged.

(31) *Gum Solution.*—Used for imbedding purposes in making cross-sections of fibers. According to Meyer it is prepared by dissolving 16 grams of the best gum Arabic in 32 cc. of water; filter through muslin into a weighed porcelain dish, add 2 grams of glycerol and then evaporate down to 24 grams. In using this gum a bundle

of fibers is arranged in as parallel a form as possible, then saturated with the gum solution and well dried. The stiff mass of gum-imbedded fibers is then clamped tightly between two pieces of cork and suitable cuts are made with the razor of a microtome.

(32) *Congo Red.*—Behrens uses a solution of Congo Red in hot water made slightly alkaline with soda ash for the staining of flax and hemp fibers, as these yield strongly dichroic colors for observation. By observation of the stained fibers under the polarising attachment of the microscope the structure of the fiber may be seen. The colors are weaker in the case of straw, esparto, wood and jute, while cotton shows hardly any.

(33) *Copper-glycerol Solution.*—Used by Silbermann and Truchot for the distinction between artificial and natural silks. Dissolve 10 grams of copper sulfate in 100 cc. of water, then add 5 grams of glycerol and sufficient caustic potash solution to completely dissolve the precipitate that is at first formed.

(34) *Litmus Paper.*—Both red and blue are useful. Employed to distinguish between vegetable and animal fiber in the dry distillation test; the gases evolved from vegetable fibers being acid in character and those from animal fibers alkaline.

(35) *Malachite Green.*—Used by Behrens in an aqueous solution slightly acidulated with acetic acid. This solution colors silk, wool, jute and woody fiber fast to water; hemp and Manila fibers partly fast; flax, cotton, straw, esparto and pure cellulose give colors readily washed out. Klemm uses a saturated aqueous solution of Malachite Green containing 2 percent of acetic acid for the determination of the lignification of wood cellulose. Completely bleached cellulose shows scarcely any color; half bleached appears a sky blue; and the unbleached cellulose is colored a deep green.

(36) *Methylene Blue.*—Also used by Behrens to distinguish between flax and cotton, and is of especial importance when combined with the oil test.

(37) *Alpha-naphthol.*—Dissolve 20 grams of the naphthol in 100 cc. of alcohol. Used to distinguish between vegetable and animal fibers. About 0.1 gram of the fiber sample is treated with 1 cc. of water, 2 drops of the naphthol solution and 1 cc. of concentrated sulfuric acid. Vegetable fiber quickly dissolves and on shaking gives a deep violet color. Animal fiber colors the liquid yellow to reddish brown.

(38) *Naphthol Yellow S.*—Used in combination with Croceine Scarlet 7BN by Behrens for the distinction between silk, wool, jute and Manila hemp. The sample of fiber is colored in a hot solution of Naphthol Yellow S containing a little sulfuric acid and then washed with hot water. It is then colored again in a cold solution of Croceine Scarlet 7BN strongly acidulated with sulfuric acid. At first the silk and later the jute and the Manila are colored red; the wool remains for a long time with a citron yellow color. Dilute ammonia will strip the color from the jute and the Manila.

(39) *Beta-naphthylamine Hydrochloride.*—Used for coloring lignified cell membranes an intense orange yellow. Dissolve a small granule of the salt in a few cc. of warm water.

(40) *Phloroglucinol.*—Dissolve 1 gram of the reagent in 80 cc. of alcohol. Used in combination with hydrochloric for the detection of lignin or to mark the presence of lignified membranes in cells (reddish violet color).

(41) *Rosaniline Sulfate.*—Used by Klemm to distinguish between sulfite and soda cellulose. A saturated solution of the salt in a 2 percent solution of alcohol is used and sulfuric acid is added gradually until a violet tone appears. With this reagent unbleached sulfite cellulose gives a deep violet red color; bleached sulfite cellulose shows a less intensive red color; unbleached soda cellulose shows about the same but weaker; bleached soda cellulose is not colored at all or only very slight red. The difference between bleached sulfite and unbleached soda cellulose is then shown by

treatment with Malachite Green, the sulfite cellulose giving a weak blue or no color at all while the unbleached soda cellulose gives a very perceptible green color.

(42) *Safranine.*—When fibers are treated with a neutral warm Safranine solution and then rinsed, silk, wool, woody tissue, and jute appear under the microscope a dark rose color; cotton a dull violet red; flax and hemp yellowish red.

(43) *Schulze's Maceration Mixture.*—This is used for isolating fiber elements. It consists of concentrated nitric acid containing a small quantity of potassium chlorate dissolved. The fiber mass is heated in this liquor and then well washed. It rapidly destroys lignin and also has a powerful action on the cellulose.

The color reactions of the vegetable fibers based on the use of chemical reagents are often not very definite and lead to inconclusive results. There have been many reagents suggested, such as ammonia and hypochlorite to characterise jute; nigrosine and cyanosine and other stains to distinguish linen from hemp and cotton, but generally these furnish only inconclusive results. The reason for this is rather easy to understand since such color reactions are generally due to the presence of incrusting substances which nearly always surround the raw fibers, but those fibers which may have undergone some treatment such as scouring or bleaching may be considerably modified in this respect, and, in fact, may be entirely devoid of foreign incrusting matter. Instead of characterising or distinguishing one vegetable fiber from another some of these chemical reagents may be usefully employed to determine if the fiber is raw or has undergone a cleansing treatment.

Some of the chemical reagents which furnish the more hopeful color reactions and which are especially useful in differentiating one group from another are the following:

(1) Nitric acid containing nitrous oxide gas. This reagent colors the so-called woody fibers (lignin) reddish brown, including straws, jute, marshmallow, Manila hemp, cocoanut, agave, New Zealand flax. It gives yellowish colors with fibers composed of woody cellulose mixed with others that are not so woody, such as esparto, stipa and pineapple. It leaves almost colorless those fibers only slightly incrusted and more or less devoid of woody substances or resinous gums, such as broom, sunn hemp, calotropis, mulberry, ramie, hemp, linen and cotton.

(2) Aniline sulfate dissolved in water gives an intense golden-yellow color to the ligneous fibers such as jute and marshmallow, an intense canary-yellow color to vegetable silks, and a pale, yellowish color to New Zealand flax, papyrifera, sunn hemp, pineapple, esparto, and stipa; only a very slight yellowish tint with Manila hemp, cocoanut and raphia; and no reaction with cotton, linen, ramie, even if in the raw state.

Since the color reactions are due to the presence of ligneous matter, the color diminishes in intensity as this becomes less or where the layers are thin; and in some cases the ligneous tissue may be covered with a

siliceous layer which greatly diminishes or entirely prevents the development of the color, as in Manila hemp, cocoanut and straw.

(3) Cochineal in alcohol solution colors cotton a light red, while linen gives a violet color.

(4) Phloroglucinol dissolved in water colors raw flax a pale reddish or yellowish which turns to a yellow in a few minutes. Raw hemp assumes a pale, red color and in a few minutes turns to a light wine red.

5. Ruthenium Red as a Reagent for Testing Textile Fibers.—Ruthenium is one of the rare metals, and is little known even to the majority of chemists. Most of its salts give an intensely red colored solution in water, and this is especially true of the ammoniacal oxychloride of ruthenium; hence the name of Ruthenium Red given to this latter compound. Its chemical formula is $Ru_2(OH)_2\ Cl_4\ (NH_3)_7+3H_2O$.

It has been found that this salt is a very convenient reagent to employ in connection with the microscopical examination of textile fibers. This is especially due to the fact that Ruthenium Red is soluble in water with a violet red color, but is insoluble in both glycerol and alcohol. On the other hand, Methylene Blue and most other coloring matters used for staining fibers in microscopic work are easily soluble in alcohol or glycerol, and as a consequence the fiber becomes decolorised when treated with these liquids. A fiber stained with Ruthenium Red, however, is not decolorised, and hence may be employed for staining in a glycerol medium.

Ruthenium Red is without action on fresh lignified tissue or that preserved in alcohol, but after the action of alkalies or of hypochlorite of soda the tissue is colored a bright rose. Schwalbe, however, has pointed out that the variations in color shades are very slight, and as a test for lignocellulose staining with Ruthenium Red is of no value, as all celluloses acquire a lilac-red color after fifteen minutes action of the reagent. Ruthenium Red colors the gums and pectin matters so widely disseminated through vegetable fibers, whereas pure cellulose (such as the normal cellulose of cotton) does not give a color. Therefore, if raw unbleached cotton is in question the fiber will be quickly colored on account of the presence of the pectin or cuticle. In the same manner, those textile fibers containing pectocelluloses, such as linen, ramie, hemp and jute are strongly colored. Raw kapok fibers are practically not stained at all.

For the testing of textile fibers the solution of Ruthenium Red may be prepared as follows: One centigram of the reagent is dissolved in 10 cc. of water. As this solution is rather unstable in strong light, it is best to prepare it in small quantities for immediate use. In the microscopic test a drop of the Ruthenium Red reagents is placed on the object glass; the fibers to be examined are then immersed in the reagent, after which the cover glass is placed in position. Since the Ruthenium Red coloration is insoluble in alcohol, the colored specimens may be preserved

in alcohol. By employing various reagents (acids, alkalies, dyestuffs, etc.) simultaneously with the ruthenium reagent some very interesting observations may be made under the microscope.

The following table exhibits the principal reactions of textile fibers with the Ruthenium Red reagent.

A. Fibers of Vegetable Origin

1. *Raw Egyptian Cotton.*—Rose color rapidly developing and becoming accentuated in time. After several hours the liquid is completely decolorised and the fiber is a violet red.

2. *Raw American Cotton.*—Same results as with Egyptian cotton, only the coloration is not as strong.

3. *Bleached Egyptian Cotton.*—No coloration. After some hours the liquid is still colored and the fibers remain colored. This is the characteristic reaction for normal cellulose of cotton.

4. *Bleached Absorbent Cotton.*—No coloration at all. Same result as above.

5. *Raw Mercerised Egyptian Cotton.*—Rapid rose coloration; after several hours becoming violet red.

6. *Bleached Mercerised Cotton.*—The fiber remains colorless, even after several hours.

7. *Bleached Cotton Mercerised Immediately Before Examination.*—The fiber is immediately colored a pale rose red, becoming accentuated to a violet red after several hours. As mineral acids decolorise the ruthenium reagent, it is necessary to be careful in these preparations to use fibers that are completely neutralised and well washed in alkaline water, and then mixed in fresh water.

8. *Filter Paper of Pure Cellulose.*—The fibers remain almost colorless, even after several hours.

9. *Ordinary White Filter Paper.*—Most of the fibers remain colorless, though some are colored a bright rose.

10. *Bleached Wood-pulp Made with Bisulfite.*—Coloration irregular and some fibers remain colorless.

11. *Raw Wood-pulp Made with Bisulfite.*—Irregular coloration; some fibers remaining colorless, though not to same extent as with the bleached pulp.

12. *Raw Soda Pulp.*—Very irregular coloration. The general tone of the color being darker than the preceding.

13. *Raw Linen.*—Fibers irregularly colored from pale rose to dark red. Some fibers remain colorless at first, then become colored.

14. *Bleached Linen.*—Fibers almost colorless; a few a pale rose.

15. *Raw Ramie.*—Fibers very slightly colored; after a few hours a general pale rose coloration.

16. *Bleached Ramie.*—No immediate coloration; after twelve hours only a slight rose color.

17. *Raw Hemp.*—Coloration irregular; from pale rose to dark red, becoming accentuated after a time.

18. *Bleached Jute.*—Coloration very clear red, becoming accentuated after a time to a violet red.

B. Animal Fibers

19. *Bleached Wool.*—Is not colored even after twelve hours' contact with the reagent.

20. *Bleached Silk.*—Also colorless at first, but after a time the filaments become colored a rose red.

C. Artificial Silk

While it is possible to distinguish nicely between artificial silk made from nitrocellulose and those made from viscose and cuprammonium solutions by means of Methylene Blue, it is not possible to differentiate between the last two silks by this reagent. By the use of the ruthenium red reagent, however, it is possible to distinguish between viscose silk and cuprammonium silk. The former fiber is colored a bright rose, while the latter remains almost colorless.

By reference to the above list of reactions, it will also be noticed that it is possible to distinguish between raw American cotton and bleached Egyptian cotton.

The behavior of various vegetable fibers with Ruthenium Red as compared with several other reagents is described by Haller.[1] The results are given in the following table:

	Cotton.	Nettle, Flax, Broom.	Hemp, Bullrush, Lupin.	Cotton Grass (Eriophormium).	Khaki Cotton.	Jute.
Iodine solution	Cellulose reaction	Cellulose reaction	Cellulose reaction	Yellow-brown color	Yellow-brown color	Yellow-brown color
Ruthenium Red	No color	Red color	Red color	—	Red color	Red color
Phloroglucinol + HCl	No color	No color	Pale rose	—	—	Red color
Maules reaction	—	—	—	—	—	+
Ferric chloride and Potassium Ferricyanide	—	—	—	Pale blue	+	+

6. General Tests for Vegetable Fibers.—A large number of the textile vegetable fibers (from either bast or leaf tissues) are more or less lignified—that is to say, a part of the fiber is changed somewhat into woody tissue. This affords a means of distinguishing certain fibers from others, or rather one class of fibers from another. If a lignified fiber is treated with a solution of indol and then with hydrochloric acid, a red color is produced. Aniline sulfate or hydrochloride, as well as many other similar compounds, colors lignified tissues a golden yellow, especially is subsequently treated

[1] *Färb. Zeit.*, 1919, pp. 29 and 43.

with dilute hydrochloric acid. Phloroglucinol and hydrochloric acid give a red color; naphthylamine hydrochloride an orange color, etc. It is to be remarked, however, that not infrequently cross-sections of the fibers though strongly lignified give scarcely any color at all with the specific woody fiber reagents. Jute is an example of this; for with phloroglucinol or indol and hydrochloric acid it scarcely gives any color, while with iodine and sulfuric acid it gives a beautiful yellow color; although when viewed lengthwise it shows a strong lignification.

If single bast or sclerenchymous fibers (from leaf tissue) are to be investigated, the fiber bundles must be disintegrated into their constituent parts by maceration. This can be accomplished by boiling the fibers with dilute nitric acid, or with Schulze's mixture (nitric acid mixed with potassium chlorate), or with caustic potash. By this treatment, however, the woody matter is destroyed, and the fibers are somewhat swollen (especially with caustic potash), so that their microchemical reactions are affected, as well as their diameters. The separation of the fiber bundles into their elements may also be undertaken on the object slide by treatment with cold chromic acid solution. This solution is allowed to act for several minutes, then water is added, and the fiber elements are finally separated from one another completely by squeezing down the cover glass. By the use of this method there is no swelling to distort the fiber, but the woody matter is dissolved as when nitric acid is used. The method of Vetillard appears to be a very good one, since by its use the microchemical reactions are not affected. The method consists in boiling the fibers to be tested with a 10 percent solution of soda or potash for about one-half hour, then washing well in water, and rubbing between the fingers, when a complete disintegration is effected and objectionable attached matter is also removed. The fibers so treated can then be mounted in glycerol or subjected to the iodine and sulfuric acid reaction.

The observation of the cross-section, which is essential to the thorough study of the fibers, requires the preparation of thin sections. In order to do this a small bundle of fibers is arranged as parallel as possible, and then impregnated with a thick solution of glycerol containing dissolved gum, after which it is allowed to thoroughly dry. The gum solution should contain neither too much nor too little glycerol. If the former, the bundle of fibers will not harden, and if the latter, it will crack on drying and break during treatment in cutting the cross-section. The bundle of fibers is laid between two corks, and pasted in securely and tied. By means of a sharp razor thin cross-sections may be cut at will, which as far as possible should be cut perpendicular to the axis of the fibers.

7. Distinction between Animal and Vegetable Fibers.—The simplest and most ready test for this purpose, when the fibers can be separated from each other, is to burn a sample of the material. The animal fibers

(wool and silk) will emit a strong empyreumatic odor of burning feathers, whereas the vegetable fibers (cotton, linen, etc.) will give off no such disagreeable odor, but only pungent and somewhat acrid fumes similar to those from burning paper. In cases where animal and vegetable fibers are mixed together and cannot readily be separated, the burning test, of course, fails for the detection of the vegetable fiber, though the presence of the animal fiber will be made evident.

A delicate reaction [1] for detecting the presence of vegetable fibers in wool is the following: The sample of material under examination is well boiled with water to remove any finishing materials that might be present and interfere with the reaction. Then a small portion of the sample is put in a test-tube with 1 cc. of water and 2 drops of an alcoholic solution of alpha-naphthol and about 1 cc. of concentrated sulfuric acid. If vegetable fibers are present, they will be dissolved and the liquid will acquire a deep violet color when shaken; the animal fibers only give a yellow to reddish brown coloration but no violet tint. If thymol is used instead of alpha-naphthol, a beautiful red coloration will be produced in the presence of vegetable fibers.

Cross and Bevan have also devised a delicate test which is serviceable for detecting the presence of vegetable fibers in fabrics; the sample of the cloth is immersed in a solution of ferric chloride, squeezed, and then placed in a solution of potassium ferrocyanide, when any vegetable fiber present will be colored blue.

Lieberman gives a test to distinguish between animal and vegetable fibers as follows: The fibers are boiled with a solution of Magenta which has previously been decolorised by the addition of just sufficient caustic soda; then they are well washed and placed in water slightly acidulated with acetic acid. If the fibers are of animal origin, they will be colored a deep pink, whereas cotton and linen fibers will be unaffected.

Both this reaction and the one with picric acid (see Table II) are convenient to use when it is desirable to render visible the animal fibers in a mixed yarn or fabric. In case of a mixture of wool and silk fibers, the wool may readily be shown by placing the sample in a very dilute boiling solution of caustic soda containing a few drops of lead acetate solution. Any wool present will be turned brown by this treatment, due to the formation of lead sulfide from the sulfur which forms a constituent of this fiber. Silk (and also cotton or other vegetable fiber) will not be colored. In this test, of course, it will be necessary that the sample is undyed, or, at least, that all coloring matters originally present be completely removed.

[1] Molisch, *Dingl. Polyt. Jour.*, 1886, vol. 261, p. 135.

In strong, cold sulfuric acid silk quickly turns yellow and dissolves; cotton disintegrates slowly without color; flax and hemp make a black mixture, and wool is scarcely affected. Both silk and wool turn yellow and are soluble in nitric acid, the first more speedily, while vegetable fibers are slightly affected.[1]

Behrens furnishes the following color test to distinguish the several important fibers. It depends on the relative reactions of these fibers with solutions of Malachite Green and Benzopurpurine, and is carried out as follows: The mixture of fibers is dyed for fifteen minutes in a warm solution of Malachite Green, then washed until no more color is extracted. It is then steeped for twenty minutes in a cold solution of Benzopurpurine, and thoroughly washed again. The following results will appear:

(*a*) Silk, wool, and jute (or other strongly lignified vegetable fiber) will be colored green. The silk will be dyed a light green and the wool and jute a dark green.

(*b*) Hemp and Manila hemp (or other slightly lignified vegetable fiber) will be colored dirty grayish brown (mud color).

(*c*) Cotton and linen will be colored red. The cotton will show a light red color while the linen will be dark red.

An interesting qualitative test to distinguish silk from wool and vegetable fibers is the following given by Lecomte:[2] A small portion of the fabric to be examined is soaked in dilute nitric acid (100 grams per liter) and then treated gradually with constant stirring during three minutes with 30 cc. of sodium nitrite solution (50 grams per liter). After ten minutes the fabric is well washed and cut into two equal portions. The first of these is treated for one hour with 40 cc. of a cold solution of sodium plumbite and sodium naphtholate. This solution is prepared by dissolving 50 grams of sodium hydrate in 500 cc. of water, and gradually adding 25 grams of lead sub-acetate dissolved in 300 cc. of water. When the resulting solution is clear 5 grams of beta-naphthol are added and the solution diluted to 1 liter. The second portion of the fabric is treated with 40 cc. of a solution containing 50 grams of sodium hydrate, 25 grams of lead sub-acetate and 2 grams of resorcin per liter. After treatment for one hour both portions are washed for fifteen minutes in water, then soaked in dilute hydrochloric acid (5 grams per liter) again washed thoroughly, then pressed between filter-paper and finally dried in the dark. When examined under the microscope the silk fibers will appear of a reddish color, the wool fibers will be black, and the vegetable fibers colorless.

Allen summarises in Table III the reactions to distinguish silk qualitatively from other fibers.

[1] Seaman, *On the Identification of Fibers.*

[2] *Jour. Pharm. Chem.*, 1906, p. 447.

TABLE III

Test.	Silk, Wool, Fur, or Hair.		Cotton or Linen.
Heated in a small test-tube	Brittle, carbonaceous residue, and odor of burnt feathers. Gases and condensed moisture alkaline to litmus		Charring and smell of burning wood. Gases and condensed moisture acid to litmus
Boiled on a saturated aqueous solution of picric acid and rinsed in water	Dyed yellow		Unchanged
Boiled with Millon's reagent	Red coloration		No change of color
Treated with cold nitric acid (1.2 sp. gr.)	Colored yellow		No change of color
Moistened with dilute hydrochloric acid and dried at 100° C.	Unchanged		Becomes rotten
	Silk.	Wool, Fur, or Hair.	
Heated to boiling with hydrochloric acid	Dissolved	Swells, without at once dissolving	Mostly undissolved
Boiled with a conc. solution of basic zinc chloride	Dissolved	Unchanged	Unchanged
Treated with cold Schweitzer's reagent	Dissolved; not precipitated by addition of salts	Undissolved; dissolves on heating	Dissolved; solution precipitated by addition of salts
Treated in the cold with 10 percent caustic soda	Undissolved	Dissolved	Undissolved
Boiled with a 2 percent solution of caustic soda	Dissolved; solution not darkened by lead acetate; negative reaction with sodium nitroprusside	Dissolved; solution gives black or brown precipitate with lead acetate and violet color with sodium nitroprusside	Unchanged
Behavior with Molisch's test	Dissolved, with little coloration	Undissolved, with yellow or brown coloration	Dissolved with deep violet color

8. Analytical Reactions of Vegetable Fibers.—The following analytical table showing the reactions of the more important vegetable fibers is given by Dodge:

TABLE IV

Fiber.	Iodine and Zinc Chloride.	Iodine and Sulfuric Acid.	Cuprammonium.	Aniline Sulfate.	Phloroglucinol.
Cotton	Violet	Blue	Blue solution	—	—
Flax	do.	do.	do.	—	—
Hemp	do.	do.	do.	Pale yellow	Violet red
Jute	Brown yellow	Green blue	do.	Golden yellow	Deep red
Ramie	Dull violet	Dull blue	do.	—	—
Manila hemp	Yellow to violet	—	—	Yellow	Red
New Zealand flax	Golden yellow	Green blue	Bluish	Yellowish	Pale red
Aloe	Yellow to brown	Yellow	Swells; bluish	do.	Pink
Cocoanut	do.	—	—	Bright yellow	Purplish

The solution of iodine and zinc chloride is prepared by taking 100 parts of zinc chloride solution of 1.8 specific gravity, adding 12 parts of water and 6 parts of potassium iodide, then add iodine until vapors of the latter begin to form. The brown liquid thus obtained should be preserved away from light. The cuprammonium solution is made by adding sodium carbonate to a solution of copper sulfate, whereby a mixed precipitate of copper hydrate and carbonate is obtained. This is well washed, and treated with just sufficient ammonia (of 0.91 specific gravity) to dissolve it. The solution should be well shaken and filtered before using. The aniline sulfate is used as a 1 percent solution; this reagent colors cells of woody fiber pale to deep yellow in proportion to the amount of woody matter present. The phloroglucinol reagent is applied as follows: first a drop or two of a 5 percent solution of phloroglucinol in 95 percent alcohol is applied to the fiber under examination, and this is followed by the addition of a couple of drops of strong hydrochloric acid. Lignified cells will be stained red, while those not lignified will remain colorless. A similar solution of aniline hydrochloride may be substituted for the phloroglucinol, in which case the lignified tissue will be stained yellow

instead of red. The iodine and sulfuric acid is applied in a manner similar to that described on a previous page.

In an examination of a sample the fibers should be separated into their ultimate cells by soaking in caustic alkali, then rubbing between the fingers, or teasing out with needles. If the separation of the cells is difficult by this means recourse must be had to boiling the fiber in a 10 percent solution of caustic soda or Labarraque's solution (sodium hypochlorite), and then fraying the fiber apart by rubbing in a mortar. After the fiber has been divided into its ultimate cells, they should be spread out on a slide moistened with glycerol; this will lessen the tendency of the cells to curl up. A cover-glass is then laid on, and the microscopical examination is made. In order to make an examination of the section of the fiber to determine the diameter of the cells, the following method is recommended: An imbedding mass is made by dissolving 70 grams of clean gum arabic in an equal weight of distilled water; then 4 grams of isinglass (gelatine) are digested in 16 cc. of cold water till swollen, and heated to complete solution. One-half of this latter solution is strained through a piece of fine muslin (the rest is discarded) and mixed with the solution of gum arabic; 10 to 12 cc. of glycerol are added, the whole is well mixed and warmed. It is best preserved in small bottles containing a fragment of camphor. On cooling the mixture solidifies, but when it is to be used the bottle is warmed, a small bundle of fibers for examination are tied together and saturated with the glue, drawing the fibers out carefully till they are straight and parallel. The bundle is then hung up and dried for twelve hours, after which it will be firm enough to cut with a microtome. The slices thus obtained are placed on a slide, and moistened with the iodine solution; this dissolves the glue, which is absorbed by strips of blotting-paper and thus removed. With soft fibers that are easily cut, a section may be more simply obtained by soaking in melted paraffin, and, after cooling, cutting on the microtome. The wax may be removed from the section by dissolving in benzene or turpentine.

In the cutting of the fiber cross-sections with the microtome, care must be had not to slice the cutting too thin; for in the color reactions that are to be subsequently obtained with the sections, satisfactory color distinctions will not be observed if the section is too thin, as there will not be sufficient depth of color. On the other hand, the sections must not be too thick as they will then be hard to properly observe in the mount and the color will be too dense and opaque for proper comparison.

Table V shows the reaction of the various vegetable fibers with the iodine-sulfuric acid reagent, together with the length and diameter of the ultimate fiber-cells in millimeters.

TABLE V

Common Name.	Botanical Name and Reaction with Iodine-Sulfuric Acid Reagent.	Length of Cells, Mm.			Diameter of Cells, Mm.			Remarks.
		Min.	Aver.	Max.	Min.	Aver.	Max.	
	Dicotyledons giving blue reaction:							
Flax	*Linum usitatissimum*	4	30	66	0.022	0.055	0.037	Cavity fine; yellow line
Hemp	*Cannabis sativa*	5	25	55	0.016	0.022	0.050	Striated; yellow sheath
Hop	*Humulus lupulus*	4	10	19	0.012	0.016	0.018	
Nettle	*Urtica* sp	4	27	55	0.020	0.050	0.070	
China grass	*Bœhmeria nivea*	20	60	200	0.050	0.080	—	
Paper mulberry	*Broussonetia papyrifera*	6	15	25	0.025	0.030	0.035	
Sunn	*Crotalaria juncea*	4	7.8	12	—	—	—	Canal scarcely apparent
Broom	*Cytisus scoparius*	2	6	9	—	—	—	Yellow envelop
Spanish broom	*Spartium junceum*	5	10	16	—	—	—	
White clover	*Melilotus alba*	5	10	18	—	—	—	Cavity large
Cotton	*Gossypium* sp	10	25	40	—	—	—	Flattened and twisted
	Dicotyledons giving yellow reaction:							
Hibiscus	*Hibiscus* sp	2	5	6	0.014	0.021	0.033	Color more intense on surface
Linden	*Tilia* sp	1.25	2	5	0.014	0.016	0.020	Canal very small
Jute	*Corchorus* sp	1.5	2	5	0.020	0.020	0.025	Stiff; canal prominent
Lace bark	*Lagetta lintearia*	3	5	6	0.010	0.015	0.020	
Willow	*Salix alba*	—	3	3	0.017	0.022	0.030	
	Monocotyledons giving blue reaction:							
Esparto	*Lygeum spartum*	1.3	2.5	4.5	0.012	0.016	0.020	
Spanish grass	*Stipa tenacissima*	0.5	1.5	3.5	0.007	0.013	0.018	Curly; cavity small
Pineapple	*Ananas sativa*	3	5	9	0.004	0.006	0.008	Cavity fine; coloration slight
	Monocotyledons giving yellow reaction:							
New Zealand flax	*Phormium tenax*	5	9	15	0.010	0.015	0.020	Coloration intense
Adam's needle	*Yucca* sp	4	5	6	0.010	0.015	0.020	
Bowstring hemp	*Sansevieria* sp	1.5	3	6	0.015	0.020	0.026	
Century plant	*Agave americana*	1.5	2.5	4	0.020	0.024	0.032	
Manila hemp	*Musa textilis*	3	6	12	0.016	0.024	0.032	

9. Micro-analytical Tables for Vegetable Fibers.—The following micro-analytical tables have been adapted from Höhnel for the qualitative determination of vegetable fibers.

I. TABLE FOR THOSE VEGETABLE FIBERS BOTANICALLY DESIGNATED AS HAIR STRUCTURES

1. (*a*) Each single fiber consists of a single cell.....(see 4)

(*b*) Each fiber consists of two cells, namely, a short, thick, underlying cell, and an overlying pointed, principal cell. The fibers are grayish brown, scarcely 0.5 cm. long; hard, woolly, lifeless, thin-walled, but round-stapled. Such fibers form the thick upper coating on the leaves of the *Cycadæ macrozamia* of New South Wales, and are used as vegetable hair in upholstery.

(*c*) Each single fiber consists of a series of cells, hence is a cellular fiber. The cells are golden yellow to brown in color, generally clinging together and empty. The fiber as a whole is highly lustrous, but very harsh and brittle; very thin-walled, flat and ribbon-shaped; frequently twisted on its axis; broad and 0.5 to 2 cms. long. Such fibers form the thick coating on the leaves of various ferns (*Cibotium*) in Asia, Australia, and Chili. The material is used for upholstery under the name of *pulu* (Fig. 377).

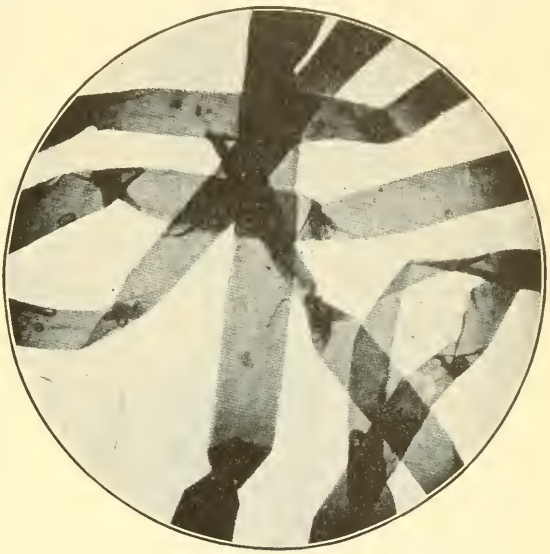


FIG. 377.—Vegetable Silk from *Cibotium glaucum*. (Solaro.)

(*d*) Each fiber consists of numerous cells growing side by side, or of several series of such; forms the so-called tuft.....(see 2)

2. (*a*) Hairs straight, stiff; white to dirty yellow in color.....(see 3)

(*b*) Hairs woolly, tough, brownish violet in color, 4 to 6 mm. long; consisting of long cotton-like, flat, twis ed, spiral cells, the walls of which are frequently thick and undulating; the contents of the cells moderately abundant, yellow to violet, and in part colored red with hydrochloric acid. This fiber covers the small, egg-shaped, flattened fruit of the New Holland plant *Cryptostemma calendulaceum*. It is used in Australia as a stuffing material.

(*c*) Hairs, woolly harsh, reddish yellow in color; the cells are very thin-walled, colorless, and generally empty; in places, however, filled with a homogeneous reddish yellow substance; where two cells come together side by side there are to be noticed round spots. The individual cells are relatively broad, extremely varied and irregularly thick; irregularly bent in places and frequently knitted together. This fiber forms the coating of a plant (*Hibiscus ?*) growing in Cuba; as employed for upholstery materials it goes by the name of *Majagua*.

3. (*a*) The hairs are 1 to 3 cm. long, and on the average are under 50 microns wide; they consist of two layers of cells which grow into one another. The inner walls are rough; the outer walls are thin and indented, hence lie close against the inner portion; the section walls are quite noticeable and thick; the tufts end in 2 to 6 pointed, often hook-shaped cells; the end cells show numerous pores; weakly lignified. This fiber consists of the ripe fruit spicula of cotton grass, *Eriophorum angustifolium*, *E. latifolium*, etc. . . . . *Cotton grass* (Figs. 378, 379)

FIG. 378.—Cotton Grass (*Eriophorum angustifolium*). (Dodge.)

FIG. 379.—The Lesser Cotton Grass (*Eriophorum latifolium*). (Dodge.)

(*b*) The fibers are 5 mm. long; mean breadth of the tufts 8 to 16 microns, the widest being under 30 microns; the tufts do not end with sharp-pointed cells; the section-walls under low magnification appear as little knots and are usually quite noticeable. This fiber is obtained from the small, lance-like fruit of the reed mace, *Typha angustifolia*, which grows on a small shaft, and carries the hairs on the other end. It is used for upholstery and other filling material. . . *Reed-mace hair* [1] (Fig. 380)

[1] Reed-mace hair is also known as *perigon hair;* it is made into a good quality of felt. The fiber consists of a few series of cells, elongated and thin-walled. The cell-walls project in a tooth-like manner, especially near the point of the fiber. The fiber is slightly lignified.

4. (*a*) The fibers are flat, woolly, frequently twisted in a spiral manner on their axes; not lignified.....(see 5)

(*b*) The fiber is generally cylindrical, stiff, not twisted; somewhat lignified, hence colored red with indophenol or phloroglucinol.....(see 6)

5. (*a*) Fibers 1 to 5 cm. long; white to yellowish brown; 12 to 42 microns thick.
Cotton (Fig. 381)

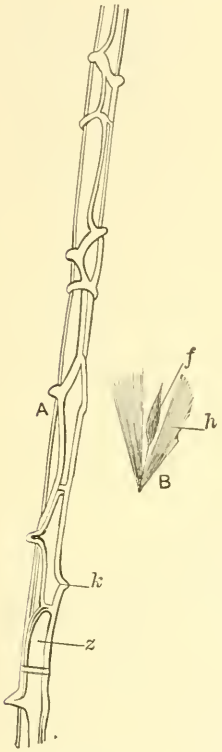


Fig. 380.

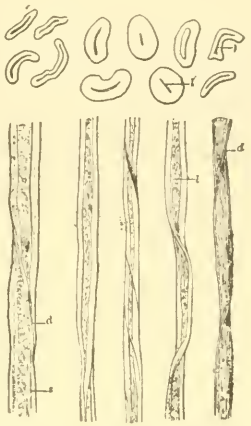


Fig. 381.

Fig. 382.

Fig. 380.—Reed-mace Hair. (×340.) (Höhnel.) *A*, Portion of hair; *B*, ripe fruit at *f*; *h*, hair around fruit; *z*, cells; *k*, knotted structure.

Fig. 381.—Cotton Fibers. (×170.) Various cotton fibers with sections above. *l*, Lumen; *d*, twists; *s*, granulations on cuticle. (Höhnel.)

Fig. 382.—Fibers of Cotton Grass or Vegetable Silk. The sharp fractures show the brittle nature of the fiber. (Micrograph by author.)

(*b*) Fibers only 9.5 cm. long; very thin; usually consisting of tufts; violet-brown in color. See above, under 2 (*b*).....*Cryptostemma hairs*

6. (*a*) The product consists of grassy spicula with a hairy covering; the hairs are 5 to 8 mm. long and about 10 to 15 microns wide; the thickness of the wall of the thick, cylindrical-pointed hairs remains rather uniform up to the point itself, hence

the latter appears very thick; spots are often observed. This fiber is upholstery material from *Saccharum officinale*.....*Sugar-cane hairs*

(*b*) The product consists of short white fibers, about 8 to 24 microns in width, and of oval, flat fruit-shells, 4 mm. wide and 5 mm. long; the hairs are broadened at the base, hence generally knife-shaped; thick-walled, with transverse, fissure-like marks; the upper portion of the hair is very thin and rough-walled; colorless; the ends are usually blunt and contain a granular matter; slightly lignified, especially at the base.

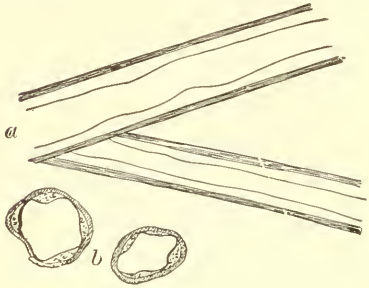


FIG. 383.—Fiber of *Strophanthus*. (×300.) *a*, Longitudinal view; *b*, cross-section. (Micrograph by author.)

Poplar cotton

(*c*) The product consists entirely of hairs and is almost entirely free from accidental impurities.....*Vegetable down and silk*

7. (*a*) The fibers have two to five longitudinal ridges on the walls, which are either crescent-shaped or quite flat, running into network at the base; these ridges are broad and difficult to discern in a surface view of the fiber, yet sometimes very apparent; the maximum thickness about 35 microns; white or yellowish in color. These fibers are the seed-hairs of *Apocynum* and *Asclepias*.

Vegetable silk (Fig. 382)

(*b*) The fibers are without ridges; transverse ridges frequently at the base or as a network. Maximum thickness generally under 35 microns; yellowish to brown. These fibers consist of the hairs which cover the fruit-pods of *Bombaceæ*.

Vegetable down (see 13)

8. (*a*) The hairs are 3.5 to 4.5 cm. long, and the largest are 50 to 60 microns in diameter.....(see 9)

(*b*) The fibers are 1.5 to 4 cm. long, and the largest are 35 to 45 microns in diameter. (see 10)

9. (*a*) The fibers are narrowed at the base, and directly above are strongly swollen, and up to 100 microns in thickness; numerous pores at the base; the fibers grow brush-like on a stem, are yellowish and harsh. This is vegetable silk from Senegal.

Strophanthus (Fig. 383)

(*b*) The fibers are white, firm, and tough, not harsh; form a hairy tuft or crown. This is vegetable silk from India.....*Beaumontia grandiflora* (Fig. 384)

(*c*) Yellow rod fibers, weak, stiff, straight, and harsh....*Calotropis procera*, Senegal

10. (*a*) At base of the hair there are spots or pores.....(see 11)

(*b*) Spots or pores lacking. Vegetable silk from *Asclepias cornuti, curassavica*, etc. (Fig. 385)

This plant grows in tropical and sub-tropical America, and is also found in India. Its seed-hairs are said to be stronger than those of most other varieties of such fibers.

11. (*a*) Spots large; round or oblique; the walls of the fiber are not thicker at the base than at the upper portion; the ridges on the fiber are remarkably well developed, the hairs are strongly bent back at the base. Vegetable silk from *Calotropis gigantea*.

(*b*) Spots small, no longitudinal markings; walls thicker than the foregoing fiber; ridges less noticeable and often apparently lacking.....(see 12)

12. (*a*) Hairs narrowed at the base.....*Hoya viridiflora*

(*b*) Hairs not narrowed at all, or scarcely so.....*Marsdenia*

13. (*a*) The hairs have mesh-like ridges at the base situated obliquely or have spiral ridges.....(see 14)

(*b*) Without mesh-like ridges at the base.....(see 15)

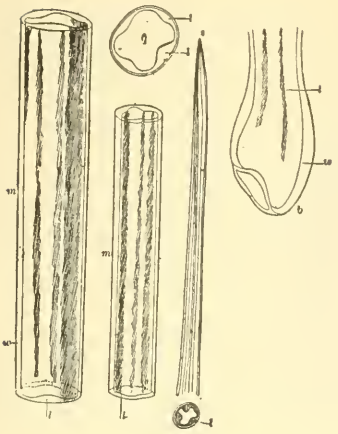


Fig. 384.

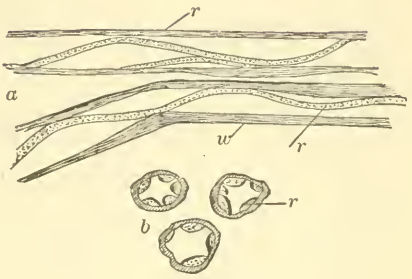


Fig. 385.

Fig. 384.—Vegetable Silk from *Beaumontia grandiflora*. (×170.) *b*, Base of fiber; *s*, pointed ends; *q*, cross-section; *m*, middle portion of fiber; *w*, cell-wall; *l*, longitudinal ridges. (Höhnel.)

Fig. 385.—Vegetable Silk from *Asclepias cornuti*. (×300.) *a*, Longitudinal view; *b*, cross-sections; *r*, thickened ridges; *w*, cell-wall. (Micrograph by author.)

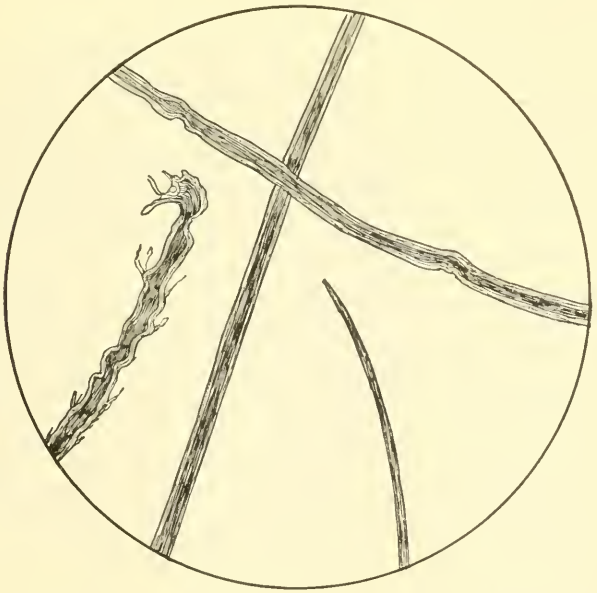


Fig. 386.—Vegetable Down (*Bombax ceiba*). (×300.) (Micrograph by author.)

14. (*a*) Base broader, thin-walled, with oblique, mesh-like ridges or spiral swellings, which often extend to a considerable distance. Points very thin-walled, gradually tapering, not ended sharply; frequently containing a reddish brown homogeneous granular substance; fiber not very stiff, usually notched. Base contains no marrow. *Vegetable down from Eriodendron anfractuosum.*

(*b*) Quite similar, but the ends are not so tapering; without marrow; whole fiber somewhat rough-walled. *Vegetable down from Bombax heptaphyllum.*

(*c*) Very similar to (*a*), but walls of fiber are quite roughened and contain at intervals throughout its length a granular marrow; base thick-walled, mesh-like fibrous ridges, but neither spirally developed nor very broad—at most only one-sixth of the width of the fiber; ends, as before, thick-walled. *Vegetable down, Ceiba cotton, from Bombax ceiba.* (Fig. 386)

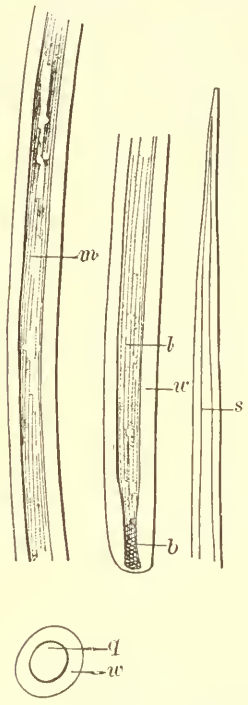


Fig. 387.—*Ochroma lagopus.* (×340.) (Höhnel.) *m*, Middle part of fiber; *b*, base; *s*, pointed end; *l*, lumen; *q*, cross-section; *w*, cell-wall.

15. (*a*) Raw fiber, brown, rough-walled; walls, 1 to 7 microns thick; not indented; points without marrow; stiff and very sharp at end; base not broadened, often contains granular matter. *Vegetable down from Ochroma lagopus*.....(Fig. 387)

(*b*) Raw fiber, yellowish, thin-walled, walls very uneven in thickness; frequently weakly developed longitudinal ridges; just at the base the wall is very thick. *Vegetable down from Cochlospermum gossypium.*

II. GENERAL TABLE FOR THE DETERMINATION OF THE VEGETABLE FIBERS

Including cotton, as well as the more important fibers derived from bast or sclerenchymous tissues.

A. Fibers Colored Blue, Violet, or Greenish with Iodine and Sulfuric Acid.

(*a*) Bast fibers and cotton. (Cotton, flax, hemp, sunn hemp, ramie, Roa fiber.)

I. The cross-sections become blue or violet with iodine and sulfuric acid; show no yellowish median layer; the lumen is often filled with a yellowish marrow.

1. *Cross-sections:* they occur either singly or in small groups; the single sections do not join over one another; are polygonal, and have sharp edges; iodine and sulfuric acid colors them blue or violet; they show closely packed, delicate layers; the lumen appears as a yellow point.

Longitudinal appearance: with iodine and sulfuric acid, quite blue; it appears transparent, quite uniformly thick; smooth or delicately marked; joints frequent; indications of dark lines running through, which are usually crossed; enlargements on the fiber, especially at the joints, frequent; the lumen appears as a narrow yellow line; the natural ends of the fibers are sharply pointed; length 4 to 66 mm., thickness 15 to 37 microns.....*Linen or Flax* (Fig. 388)

2. *Cross-sections* single or very few in a group, loosely held together; polygonal or irregular, mostly flat, very large; colored blue or violet with iodine and sulfuric acid;

stratification not noticeable; the lumen is large and irregular; frequently filled with a dark yellow marrow; radial fissures frequently apparent.

Longitudinal appearance: many of the fibers remarkably broad; the width of a single fiber very uneven; smooth or striped; very often ruptures in the wall; with iodine and sulfuric acid, blue or violet; the lumen readily seen; very broad, often containing a dark yellow marrow; joints noticeable; dark, transverse lines frequent, often crossing each other; the ends are relatively thick-walled and blunt; length 60 to 250 mm., thickness up to 80 microns.

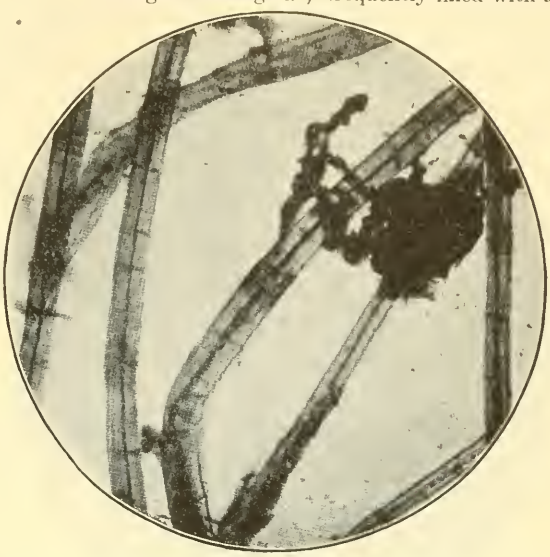


FIG. 388.—Raw Linen Treated with Iodine and Sulfuric Acid. (Solaro.)

China grass, Ramie

3. *Cross-section:* not many in the groups; polygonal; mostly with straight or slightly curved sides and blunt angles; the lumen is contracted lengthwise regularly; frequently contains a yellow marrow, many sections are surrounded by a thin, greenish colored layer; not closely joined to one another. The sections often show very beautiful radial marks or fissures and concentric layers; the various layers are colored differently.

Longitudinal appearance, as with China grass; proportional dimensions similar.

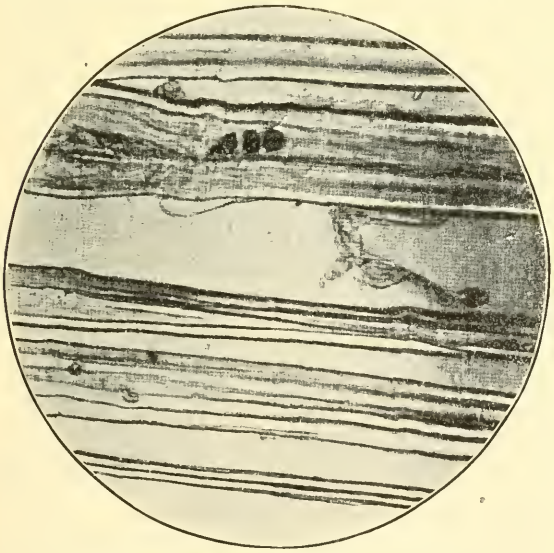


FIG. 389.—Raw Ramie Fiber. (Solaro.)

Roa fiber

4. *Cross-sections* always isolated, rounded, various shapes, mostly kidney-shaped; with iodine and sulfuric acid, blue or violet; lumen contracted, line-shaped, often containing a yellowish marrow; no stratification.

Longitudinal appearance: fibers always separate; with iodine and sulfuric acid, a fine blue; streaked and twisted; lumen broad, distinct, frequently contains yellowish marrow; ends blunt;

the entire fiber not soluble in concentrated sulfuric acid; coated with a very thin cuticle; length 10 to 60 mm., breadth 12 to 42 microns.

Cotton, Caravonica cotton (Fig. 390)

II. Cross-section blue or violet with iodine and sulfuric acid; polyhedral, rounded or irregular; always surrounded by a yellow median layer.

Fig. 390.—Caravonica Cotton; Wool-like Type. (Solaro.)

1. *Cross-sections* always in groups, with angles more or less rounded off, lying very close to one another; all of them surrounded by a thin, yellowish median layer; the lumen is line-shaped, single or forked, often broad, with inturning edges, without marrow; good concentric stratification; the different strata being differently colored.

Longitudinal appearance: with iodine and sulfuric acid, blue, greenish, or dirty yellow; fibers irregular in thickness, frequently with appended portions of yellowish median layer; joints and transverse lines frequent; stripes very distinct; the lumen is not very apparent, but broader than linen; ends are broad, thick-walled, and blunt, often branched; length 5 to 55 mm., breadth 16 to 50 microns. . . . . *Hemp* (Fig. 391)

2. *Cross-sections* in large groups, lying very close together and touching; very similar to those of hemp; often crescent-shaped. Polygonal or oval, with lumen of varying size, frequently containing yellowish marrow; lumen usually not line-shaped, but irregular; a broad yellow median layer always present, from which the blue inner strata are easily distinguished; stratification very distinct, as with hemp.

Longitudinal appearance, as with hemp, except in dimensions, which are: length 4 to 12 mm., breadth 25 to 50 microns.

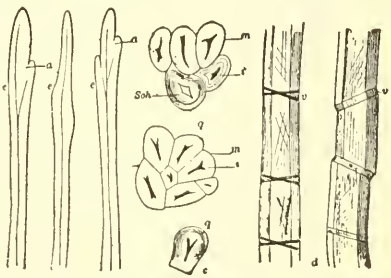


Fig. 391.—Hemp. (×170.) *b*, Ends of fibers; *c*, cross-section; *d*, longitudinal view. (Höhnel.)

Sunn hemp (Fig. 392)

(*b*) Leaf fibers. (With vascular tissue; without jointed structure. Esparto and pineapple fiber.)

1. *Cross-sections* in large, compact, often crescent-shaped groups; very small; pale blue or violet with iodine and sulfuric acid; surrounded by a thick, shell-like network of median layer; rounded or polygonal; lumen like a point or streak; thick cuttings appear greenish or even yellow; frequently bundles of vascular tissue with one or two rows of thick, yellow-colored fibers.

Longitudinal appearance: lumen often invisible, generally as a fine line; ends are tapered with needle-like points; color with iodine and sulfuric acid, blue, but often quite faint; frequently present short, thick, stiff, completely lignified fibers from vascular tissue; length 5 mm., breadth 6 microns.

Pineapple fiber

2. *Cross-sections* in groups; with iodine and sulfuric acid, mostly blue, though also yellow; often with pronounced stratification; the outer strata frequently yellow, while the inner are blue; rounded or oval, seldom straight-sided; lumen like a point.

Longitudinal appearance: the fibers are short; blue with iodine and sulfuric acid; thin, very firm, smooth, uniform in breadth; lumen yellow, line-shaped; ends are seldon pointed, mostly blunt or chiselled off, or forked; length 1.5 mm., breadth 12 microns.....*Esparto*

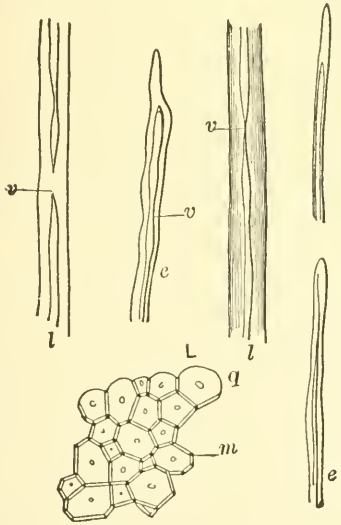


FIG. 393.—Pseudo-jute (*Urena sinuata*). (×340.) (Höhnel.) *l*, Longitudinal view; *v*, interruption of lumen; *e*, end with thick wall; *q*, cross-section; *m*, median layer; *L*, small lumen.

Fibers slender, regular, very thick-walled, smooth;

FIG. 392.—Sunn Hemp. (Solaro.)

B. Fibers Colored Yellow with Iodine and Sulfuric Acid.

(*a*) DICOTYLEDONOUS FIBERS. (Without vascular bundles; lumen showing remarkable contractions. Including jute, *Abelmoschus*, Gambo hemp, *Urena*, and Manila hemp; the latter sometimes shows vascular tissue.)

1. Cross-sections in groups; polygonal and straight-lined, with sharp angles; lumen round or oval, smooth, and without marrow, cross-sections with narrow median layers showing the same color as the inner strata with iodine and sulfuric acid; lengthwise appearance shows the lumen with contractions.

1. *Cross-sections* polygonal, straight-lined; lumen, in general, large, round, or oval.

Longitudinal appearance: fibers smooth, without joints or stripes; lumen distinctly visible; broad; with contractions; the ends always blunt and moderately thick; ends have wide lumen; length 1.5 to 5 mm., breadth 20 to 25 microns.

Jute

2. *Cross-sections* in general somewhat smaller

than jute; sides straight, with sharp angles; lumen frequently like a point or line, oval, occasionally pointed; not so large as with jute.

Longitudinal appearance: fibers quite even in thickness, smooth, with occasional joints or stripes; lumen narrow, irregular in thickness, contractions frequent; the ends are broad, blunt, frequently thickened; length 1 to 1.6 mm., breadth 8 to 20 microns.

Pseudo-jute or Musk mallow of Abelmoschus

II. Cross-sections in groups, lying close together; polygonal, with sharp lines and sharp or rounded angles; lumen without marrow; the median layer is broad, and with iodine and sulfuric acid is colored perceptibly darker than the inner layer of cell-wall; the lumen in places is completely lacking.

1. *Cross-sections* more or less polygonal, with sharp or slightly rounded angles; the lumen is small, becoming broader and more oval as the section is more rounded; the median layer is broad, and is colored considerably darker than the cell-wall with iodine and sulfuric acid; stratification occasional and indistinct.

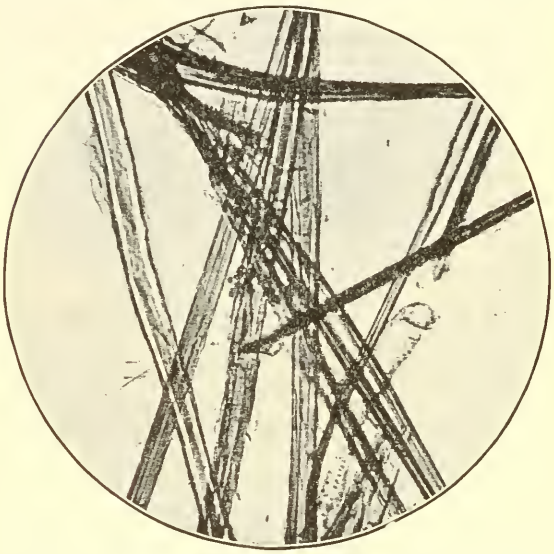


Fig. 394.—Raw Fibers of New Zealand Flax. (Solaro.)

Longitudinal appearance: the fibers vary much in thickness; lumen generally narrow, with decided contractions, and in some parts totally absent; the broader fibers often striped; ends are blunt and generally thickened; length 2 to 6 mm., breadth 14 to 33 microns.

Gambo hemp

2. *Cross-sections* always in groups; small, polygonal, with sharp angles; lumen very small, appearing as a point or a short line.

Longitudinal appearance: occasionally jointed or striped; lumen with decided contractions, in some places altogether lacking; ends blunt and sometimes thickened; length 1.1 to 3.2 mm., breadth 9 to 24 microns.

Pseudo-jute from *Urena sinuata* (Fig. 393)

(*b*) Monocotyledonous fibers. (Occurring as vascular bundles together with bast; the lumen exhibits no contractions; in Manila hemp vascular bundles often lacking. Includes New Zealand flax, Manila hemp, *Sansevicria* or bowstring hemp, Pita hemp, and Yucca fiber.)

1. Cross-sections generally rounded, occasionally polygonal; the lumen is always rounded, without contractions longitudinally; median layer indistinct, or only as a narrow line; vascular tissue small in amount, or altogether lacking.

1. *Cross-sections* small, generally rounded, lying loosely separated; very rounded angles; lumen small, round, or oval, without marrow.

Longitudinal appearance: the fibers are stiff and thin; the lumen is small but very distinct, and uniform in width; the ends are pointed; no markings and no joints; length 5 to 15 mm., breadth 10 to 20 microns. . . . . *New Zealand flax* (Fig. 394)

2. *Cross-sections* polygonal, with rounded angles, in loosely adherent groups; lumen large and round, often containing yellow marrow.

Longitudinal appearance: fibers uniform in diameter; walls thinner than those of New Zealand flax; lumen large and distinct; ends pointed or slightly rounded; silicious stegmata adhering to the fiber bundles and to be found in the ash as bead-like strings, insoluble in hydrochloric acid; length 3 to 12 mm., diameter 16 to 32 microns.

Manila hemp (Fig. 395)

II. *Cross-sections* polygonal; lumen large and polygonal, with angles quite sharp; median layer lacking or only in the form of a thin line.

1. *Cross-sections* distinctly polygonal, often with blunt angles, lying compactly together; lumen large and polygonal, with sharp angles; no stratification in cell-wall.

Longitudinal appearance: fibers thin and smooth; lumen large and distinct; ends pointed; length 1.5 to 6 mm., diameter 15 to 26 microns.

Sanscvieria fiber

2. *Cross-sections* polygonal, not many sections to a group, but lying compactly together; angles slightly rounded; lumen not very large, polygonal, often having blunt angles; besides the bast-fiber sections are to be noticed some vascular bundles in the form of large spirals.

Longitudinal appearance: fibers uniform in diameter; lumen not very large, but uniform; no structure; ends pointed and sometimes blunt; length 1.3 to 3.7 mm., diameter 15 to 24 microns.....*Aloe hemp*

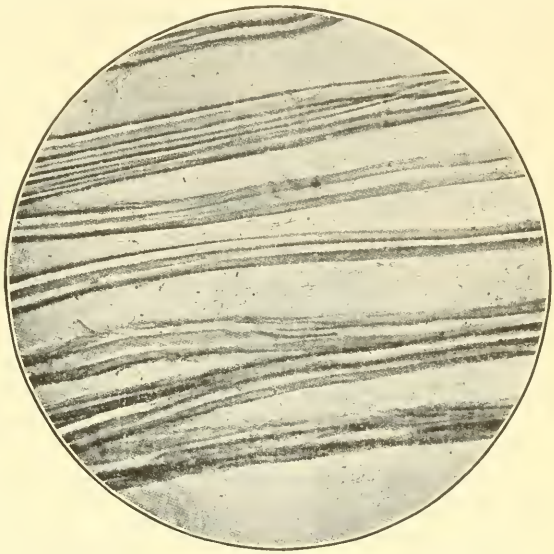


FIG. 395.—Raw Fibers of Manila Hemp. (Solaro.)

3. *Cross-sections* polygonal, with straight lines; angles sharp, though sometimes blunt; sections lie compactly together; lumen large and polygonal, though angles not so sharp.

Longitudinal appearance: fibers stiff, and often very wide toward the middle; lumen large; ends broad, thickened, and often forked; large, shining crystals to be found in the ash, which are derived from the chisel-shaped crystals of calcium oxalate clinging to the outside of the fiber; these crystals are often ½ mm. in length; length of fiber 1 to 4 mm., diameter 20 to 32 microns.....*Pita hemp*

III. Cross-sections polygonal and small, sides straight, with very sharp angles; lumen small, usually as a point or line-shaped; sections lie compactly together and are surrounded by a thick, distinct median layer.

1. *Cross-sections* as above.

Longitudinal appearance: fibers very narrow; lumen also very narrow; longitudinal ridges frequent; ends usually sharp pointed; length 0.5 to 6 mm., diameter 10 to 29 microns.....*Yucca fiber* [1] (Fig. 396)

[1] This is obtained from the *Yucca gloriosa* and belongs to the finest kind of monocotyledonous fibers. The fiber frequently shows no visible markings; the cross-

III. ANALYTICAL REVIEW OF THE CHIEF VEGETABLE FIBERS.

1. Those occurring as thick, fibrous bundles, also with vascular tissue (monocotyledonous fibers).....(see 2)

Vascular tissue absent; sections and fibers always single; round or kidney-shaped by being pressed together; fibers with a thin external cuticle insoluble in concentrated sulfuric acid, and not swelling (vegetable hairs).....(see 7)

Vascular tissue absent; the fibers are bundles of bast filaments; sections occur i g two or more together (mostly true dicotyledonous fibers).....(see 13)

2. Lumen very narrow, line-shaped, much thinner than the wall.....(see 3)

Lumen in thickest fibers almost as wide, or even wider, than the wall; completely lignified.....(see 4)

3. Sections polygonal, sides straight, with sharp angles; completely lignified; diameter 10 to 20 microns.....*Yucca fiber*

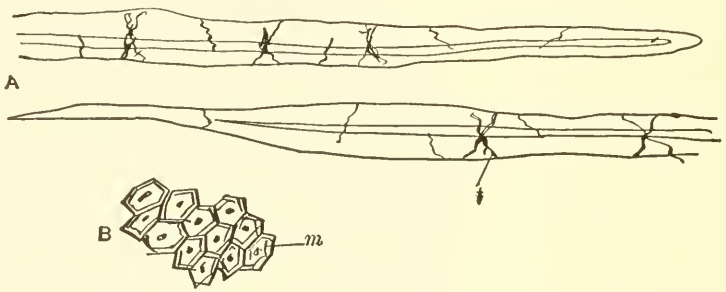


FIG. 396.—Yucca Fiber. (×400.) *A*, Longitudinal view; *B*, cross-section; *m*, median layer; *t*, transverse markings. (Micrograph by author.)

Sections rounded to polygonal; often flattened or egg-shaped; the inner strata at least not lignified; diameter 4 to 8 microns.....*Pineapple fiber*

4. Thick, strongly silicified stegmata occurring at intervals on the fiber bundles in short to long rows, sometimes but few; these are four-cornered, have serrated edges, and show a round, bright, transparent place in the middle; they are easily seen after the fiber has been macerated with chromic acid, and are about 30 microns in length; in the ash of fibers previously treated with nitric acid, they appear in the form of pearly strings, often quite long, and insoluble in hydrochloric acid; they are joined together lengthwise; the fibers are thick-walled, with fissure-like pores; 3 to 12 mm. long; the fiber bundles are yellowish and lustrous.....*Manila hemp*

Stegmata present, sometimes in small, sometimes in large quantities; they are lens-shaped, small (about 15 microns wide), and are fastened to the exterior fibers of the bundles by serrated edges; in the ash of the fiber they melt together in the form of indistinct globules; in the ash of fibers previously boiled in nitric acid they appear as yeast-cells, joined together in round skeletons of silica; the fibers are often thin-walled, with numerous pores; 1 to 2 mm. in length; the raw fibers generally brown and rough.....*Coir*

Stegmata absent, hence the fibers are not accompanied by silicified elements.(see 5)

5. Fiber bundles covered externally at intervals with crystals of calcium oxalate, at

sections are small and polygonal, with straight sides and sharp points. The median layer is very noticeable and the whole fiber is strongly lignified.

times up to 0.5 mm. in length; lustrous, with quadrangular sections, chisel-shaped at the ends, hence they appear as thick, needle-shaped crystals; when present in large numbers these crystals occur in long rows which are frequently visible to the naked eye, and always easily recognisable under the microscope, especially in the ash. The fiber-bundles are mostly thick, and their outer fibers (as a result of their preparation) frequently contain fissures or are torn; thickness of the walls very uneven; fibers often much widened at the middle..... *Pita hemp*

Without crystals, generally thin; in cross-section usually less than 100 fibers to a bundle; thickness of walls and lumen very uniform..... (see 6)

6. Sections mostly round, not very compact; lumen usually thinner than the wall, but never a single line; in section round or oval; vascular tissue in but small amount. *New Zealand flax*

Sections, on one side at least, polygonal; section of lumen polygonal, with angles more or less sharp; generally as wide or wider than the wall; vascular tissue frequent. *Aloe hemp*

7. Fibers mostly rope-shaped, twisted, externally streaked, generally possessing fine granules or marked with little lines, therefore, rough; thin to thick walls; cross-sections squeezed together, or round to kidney-shaped, hence the fiber has more or less the shape of a flat band; section of lumen more or less arched, line-shaped, frequently containing yellow marrow; consists of pure cellulose with the exception of the thin cuticle..... *Cotton*

Fibers not twisted, smooth externally, and without longitudinal markings; fibers not flat, sections round; walls generally very thin; sometimes, however, they are thick; lignified, scarcely swelling in ammoniacal copper oxide..... *Vegetable down* / *Vegetable silks* } (see 8)

8. Fibers on the inside possess from 2 to 5 broad ridges, which at times are very noticeable, at others scarcely visible; they run lengthwise in the fiber, and in section are semicircular; on this account the walls appear unequal in thickness when viewed longitudinally; the maximum thickness is about 35 microns..... *Vegetable silks* (see 9)

Fibers without ridges; maximum thickness mostly 30 to 35 microns. *Vegetable down* (see 12)

9. Largest diameters 50 to 60 microns; length 3.5 to 4.5 cm..... (see 10)

Largest diameters 35 to 45 microns; length 1.5 to 4 cm..... (see 11)

10. Fibers contracted at the lower end, and directly above abruptly swelling, becoming 80 microns thick; the under portion of the swollen area contains numerous pore-canals; fibers feather-like or brush-like arising from a straight shaft. *Vegetable silk from Senegal*

Contrary to the above the fibers originate from one point, like a fan; remarkably strong, curved backward; very firm..... *Vegetable silk from India*

Like the foregoing, but the fiber is stiff, straight, weak, and brittle. *Calotropis procera*

11. Thickened ridges very noticeable; in the cross-sections often occurring in the form of a semicircle; bound together in a strictly reticulated manner. *Vegetable silk from Asclepias cornuti*

Thickened ridges indistinct, projecting but slightly in the cross-section. *Vegetable silk from Asclepias curassavica*

12. Raw fiber, yellowish; broadened at the lower end (up to 50 microns); also reticular thickening or transverse markings; wall 1 to 2 microns thick.. *Bombax cotton*

Raw fiber brown; the lower end contracted and not showing reticulated thickenings; fiber almost altogether thin-walled, though just at the lower end very thick-walled. *Cochlospermum gossypium*

13. Thick fiber bundles, whose outer surface contains at intervals series of thick silicious plates, having sharp indented edges and a round hollow space.

Manila hemp (see under 4)

Silicious plates absent; lengthwise the lumen often exhibits remarkable contractions, while the wall is very uneven in thickness; at intervals, indeed the lumen is almost entirely interrupted; joints and transverse fissures along the fiber; transverse markings and lines, which appear somewhat like zones or knots, are completely lacking, or are very rare and indistinct; completely lignified, hence colored yellow with iodine and sulfuric acid.....(see 14)

Silicious plates absent, also remarkable contractions of the lumen; thickness of the walls very uniform; joints and fissures along the fiber, transverse lines and markings frequent, hence the fiber often appears as if it contains swollen knots; unlignified, or only lignified on the external layer of membrane, hence lengthwise the fiber is colored blue with iodine and sulfuric acid or violet or green, or at the most colored yellow in places.....(see 17)

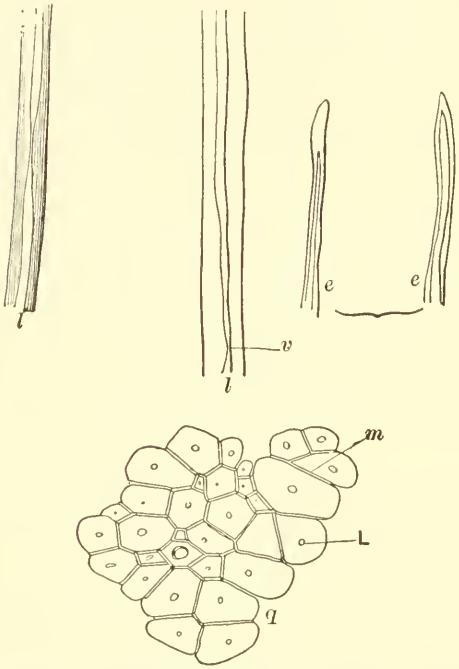


FIG. 397.—*Abelmoschus* Jute. (×325.) (Höhnel.) *l*, Longitudinal view; *q*, cross-section; *e*, ends; *L*, small lumen; *v*, narrowing of lumen; *m*, median layer.

14. Exterior layers of membrane narrow and showing the same coloration with iodine and sulfuric acid as the inner layers, hence the same as the entire cross-section the lumen hardly ever completely interrupted.

(see 15)

Median layer in sections wide; colored considerably darker with iodine and sulfuric acid; lumen often completely interrupted.....(see 16)

15. Lumen in general large, diameter as wide or only a little narrower than the wall; in section round or oval, seldom as a point; no crystals of calcium oxalate.....*True jute*

Lumen usually small, diameter much narrower than the thick wall in section frequently as a point; crystals of calcium oxalate of frequent occurrence (detected by ignition).....*Pseudo-jute* (*Abelmoschus*) (Fig. 397)

16. Lumen almost always considerably smaller than the wall; ends usually very thick-walled and narrow; calcium oxalate crystals of frequent occurrence.

Pseudo-jute (*Urena sinuata*)

Lumen frequently as wide as or wider than the wall, mostly narrower however; ends broad and blunt.....*Gambo hemp*

17. The lumen in the middle portion of the fiber generally line-shaped, much narrower than the wall; ends never blunt, always sharply pointed; sections isolated or in small groups, regular in diameter, sharp-angled and straight-sided polygonals; without separate median layer; iodine and sulfuric acid colors the entire section

blue or violet; the lumen in the cross-section is very small, or as a point, containing a marrow which is colored yellow with iodine and sulfuric acid,.....*Linen or Flax*

Lumen, at least in the central portion of the fiber, always much thicker than the walls; in section generally more or less flattened, narrow to broad, egg-shaped or oval. Fiber ends blunt, never sharply pointed; sections almost never sharp-angled polygonals, but more or less oval or elliptical, and with a rounded boundary....(see 18)

18. Breadth of fiber up to 80 microns; maximum length 15 to 60 mm.; sections always in compact groups, which often consist of many fibers, with thinner or thicker layers of membrane, which are colored yellow with iodine and sulfuric acid, hence the fiber is never colored a pure blue, but dirty blue to greenish, and in places yellow; ends often have side branches projecting.....(see 19)

19. Lignified exterior membranes very thin; lumen in section narrow, very seldom broad, fissure-like or line-shaped, often branched, without marrow.....*Hemp*

Lignified exterior layers often as wide as the interior layers, or wider; the interior layers are often loosened in places from the exterior ones where they are thin; lumen in section scarcely ever narrow or fissure-shaped, but broad, oval, or long; often containing a yellowish marrow.....*Sunn hemp*

10. Reactions of Bast Fibers.—In Table VI, by Goodale, are presented reactions for the principal bast fibers.

11. Microscopical Comparison of Various Fibers.—Zetzsche, in Table VII, gives comparisons between the principal fibers as obtained by a microscopical examination.

12. Systematic Analysis of Mixed Fibers.—Table VIII, by Pinchon, represents an attempt to give a systematic qualitative analysis of the most important textile fibers.

The fiber is first treated with a 10 percent solution of caustic potash, which causes any animal fiber to dissolve, the vegetable fibers remaining insoluble. If lead acetate solution be added to the fiber after treatment with caustic potash, and wool is present it will become dark, owing to the formation of lead sulfide from the sulfur existing in the wool. If silk be suspected, warm in concentrated sulfuric acid, which will cause the silk to darken rapidly and the wool more slowly.

With a due degree of caution, this schematic analysis may be employed with considerable success, though confirmatory tests should be applied to the detection of each fiber indicated. The differentiation between the various vegetable fibers given is especially difficult. Too much reliance, therefore, must not be placed on the accuracy of analysis depending on observations based on the reactions and measurements of these tables, unless backed up by expert judgment resulting from long experience in fiber analysis and microscopy. Particularly in the case of the vegetable bast and leaf fibers the samples will be found to be quite heterogeneous in their reactions, and would often be confused with mixtures of different fibers, when in reality they may be quite simple in their origin. The microscopist must be sufficiently experienced to give their proper values to the observations recorded, especially with regard to the microchemical reactions.

TABLE VI

REACTIONS OF BAST FIBERS

Name of Fiber.	Reaction with Schweitzer's Reagent.	Reaction with Iodine and Sulfuric Acid.	Reaction with Aniline Sulfate.	Length of Raw Fiber, Cm.	Width, Mm.	Length of Bast-cells, Mm.	Width of Bast-cells.	
							Limit, Mm.	Average, Mm.
Raw flax	Soon attacked and almost entirely dissolved	Colored blue	Remains uncolored	20–140	0.04–0.62	20–40	0.012–0.076	0.015
Raw hemp	Clean fiber dissolved	Greenish blue to pure blue	Faint yellow	100–300	—	10	0.015–0.028	0.016
Raw jute	Bluish color; more or less distinct swelling	Yellow to brown	Golden yellow to orange	150–300	0.03–0.14	0.8–4.1	0.010–0.021	0.016
Raw esparto	Bright green	Rusty red	Egg-yellow	10–40	0.09–0.50	0.5–1.9	0.009–0.015	—
Raw aloe	Bluish color; feeble swelling	Reddish brown	Golden yellow	40–50	0.075–.105	1.3–3.7	0.015–0.024	—
New Zealand flax	Bluish color; more or less swelling	Varies, with purity of fiber, yellow, green, or blue	Uncolored	80–110	0.042–0.12	2.5–5.6	0.008–0.019	0.013

TABLE VI—*Continued*

REACTIONS OF BAST FIBERS

Name of Fiber.	Reaction with Schweitzer's Reagent.	Reaction with Iodine and Sulfuric Acid.	Reaction with Aniline Sulfate.	Length of Raw Fiber, Cm.	Width, Mm.	Length of Bast-cells, Mm.	Width of Bast-cells.	
							Limit, Mm.	Average, Mm.
China grass	When "cottonised" quickly acted upon, and almost completely dissolved	Copper-red to blue	Uncolored	—	—	220	0.040–0.080	0.050
Ramie	do.	do.	do.	—	—	80	0.016–0.126	—
Coir	Perceptible swelling; blue color	Reagent not applicable on account of color of fiber	Not applicable	15–33	0.05–0.30	0.4–0.96	0.012–0.020	0.016
Agave varieties	Swells and becomes somewhat blue	With iodine sol., yellow; on addition of H_2SO_4, brown	Yellow	100	0.10–0.46	1.02–2.22	0.016–0.021	0.017
Manila	Blue color and feeble swelling	With iodine sol., yellow; on addition of H_2SO_4, greenish	Pale yellow	750	0.010–0.28	2.0–2.7	0.012–0.046	0.029

TABLE VII

Microscopical Comparison of Fibers

	Cotton.	Linen, Hemp.	Ramie.	Jute.	Manila.	Wool.	Silk.
Cotton		Knotted structure and dislocations. Strong polarisation colors. Dyed with Methylene Blue	Fiber very thick; knotted structure and dislocations. Violet stain with iodine solution alone	Irregular thickness of cell-wall. Lignified (red with phloroglucinol, yellow with chlor-iodide of zinc). Reddish brown color with chlorine and ammonia	Stegmata; crystals. Lignified (red with phloroglucinol, yellow with chlor-iodide of zinc	Epidermal scales. Stained by picric acid, or nitric acid. Yellow color with chlor-iodide of zinc Soluble in caustic soda. Empyreumatic odor on burning	Structureless, smooth cylindrical fibers. Yellow color, with picric acid or nitric acid. Yellow color with chlor-iodide of zinc Soluble in hydrochloric acid. Strong polarisation colors. Empyreumatic odor on burning
Linen, Hemp Cross-sections	Ribbon shaped and twisted Sausage-like structure with cuprammonium oxide		Greater thickness of fiber. Violet color with iodine solution alone	do.	do.	do.	do
Angular | Round							
Ends of Fibers							
Spike-Shaped | Blunt, & forked							
With iodine and sulfuric acid							
pure blue color | greenish blue color							

Ramie	do.	Smaller cross-section of fiber. With iodine solution alone yellowish brown color		do.	do.	do.	do.
Jute	do. Also violet color with chlor-iodide of zinc	Joints and dislocations. Blue color with chlor-iodide of zinc. Soluble in cuprammonium oxide	Joints and dislocations. Greater thickness of fiber. Blue color with chlor-iodide of zinc. Soluble in cuprammonium oxide		Stegmata and crystals present	do.	do.
Manila, etc.	do.	do.	do.	do.		do.	do.
Wool	do. Also no odor on burning	do. Also no odor on burning	do. Also no odor on burning	do. Also no odor on burning	Stegmata and crystals. Red color with phlorogluci-nol. No odor on burning		do.
Silk	do.	do.	do.	do.	do.	do.	
True Smooth cylinder | Wild Striated irregular						Also brown color when heated with caustic soda and lead acetate	
In cold conc. HCl							
Quickly dissolves | Slowly dissolves							

TABLE VIII

TABLE FOR ANALYSIS OF MIXED FIBERS (PINCHON)

The mixture is boiled with 10% KOH for 20 minutes

Completely dissolves			Remains undissolved			Partly dissolves		
Another sample is boiled 5 minutes with zinc chloride solution								
The whole dissolves	Part dissolves	None dissolves	None dissolves			Partial dissolves		None dissolves
The alkaline solution does not blacken on the addition of lead acetate: *Silk*	The dissolved portion is not blackened by lead acetate, but the insoluble portion does: *Silk* and *Wool*	The mass is blackened by lead acetate: *Wool*	Chlorine water (or ammonia) colors the fiber			On addition of lead acetate is		Nitric acid colors portion yellow, the residue remaining white: *Flax*, *Cotton*
			Red-brown	Not at all		Blackened	Not blackened	
			The fiber is colored red by fuming nitricacid: *New Zealand Flax*	Alcoholic fuchsine colors the fiber		Caustic potash partly dissolves the fibers insoluble in zinc chloride; the remaining fibers are soluble in ammoniacal copper oxide: *Wool*, *Silk*, and *Cotton*	Picric acid colors portion yellow, the residue remaining white: *Silk*, *Cotton*	
				Permanently	Color removed by washing			
				Caustic potash stains yellow	No yellow color with caustic potash: *Cotton*			
				Iodine and sulfuric acid color				
				Yellow *Hemp*	Blue *Flax*			

13. Reactions of Vegetable Fibers with Iodine-Sulfuric Acid Reagent.—All fibers of vegetable origin have an internal canal or cavity (lumen), and when this is observed under the microscope in connection with the color reactions obtained by treatment of the fiber with the iodine-sulfuric acid reagent certain characteristics may be noted as summarised in the following table:

(*A*) Gives blue color:
- (*a*) Isolated fibers:
  - (1) Wide canal—cotton,
  - (2) Narrow canal, often interrupted and discontinuous—mercerised cotton;
- (*b*) Filaments devoid of vesicles or spiral tubes, with fibers surrounded by incrusting strata, and attached in bundles if raw, and easily separated if bleached:
  - (1) Narrow canal—Linen, mulberry, broom,
  - (2) Wide canal—Hemp, ramie, sunn hemp, calotropis.

(*B*) Gives some blue and some yellow:
- (*a*) Filaments often having on their surface vesicles or spiral tubes, if raw, with fibers surrounded by incrusting substances and attached in bundles:
  - (1) Narrow canal—Pineapple, papyrifera, kazinoki, stipa, esparto.

(*C*) Gives yellow color:
- (*a*) Isolated fibers:
  - (1) Very wide canal—Vegetable silks;
- (*b*) Filaments often having on the surface, if raw, vesicles or spiral tubes, rarely if bleached: fibers generally closely attached to each other:
  - (1) Narrow canal thinner than fiber wall—Yucca, raphia, Panama, palm, New Zealand flax,
  - (2) Wide canal or wider than fiber wall—Manila hemp, cocoanut, agave, sisal, sansevieria, aloe;
- (*c*) Filaments devoid of vesicles or spiral tubes, with fibers attached to or surrounded by incrusting substances:
  - (1) Wide canal—Edgeworthia papyrifera, broussonetia (mulberry),
  - (2) Narrow canal—Jute, mallow.

The fibercross-sections when treated with the iodine, sulfuric acid reagent give the following reactions·

(*A*) Gives blue color:
- (*a*) Outline curvilinear:
  - (1) Section elongated and borders sinuous:
    - (*a*) Sections isolated—Cotton, mulberry, bleached ramie,
    - (*b*) Sections attached—Raw ramie, linen waste, raw hemp, sunn hemp, calotropis,
  - (2) Section rounded or slightly oval:
    - (*a*) Sections isolated—Mercerised cotton,
    - (*b*) Sections attached—Calotropis;
- (*b*) Outline polygonal:
  - (1) Section elongated and attached:
    - (*a*) Sides and angles slightly curved—Linen waste, raw hemp,
    - (*b*) Sides straight and angles sharp—Broom,

(2) Section rounded:
(*a*) Sections isolated—Bleached linen,
(*b*) Sections attached—Hemp waste, raw flax.

(*B*) Gives blue to yellow colors:
(*a*) Outline curvilinear:
(1) Section elongated and isolated—Broussonetia, kazinoki,
(*b*) Outline polygonal:
(1) Section rounded and attached—Pineapple, stipa, esparto

(*C*) Gives yellow color:
(*a*) Outline curvilinear:
(1) Section rounded or slightly oval:
(*a*) Sections isolated—Vegetable silks,
(*b*) Sections close together but not attached—New Zealand flax, Edgeworthia papyrifera,
(2) Section elongated, sides sinuous, often isolated, large lumen—Broussonetia;
(*b*) Outline polygonal:
(1) Section rounded:
(*a*) Close together but not attached, large lumen—Manila hemp,
(*b*) Sections attached, small lumen—Raphia, palm,
(2) Section quadrangular and attached—Agave, sansevieria, cocoanut,
(3) Section with straight sides and acute angles:
(*a*) Sections attached, wide lumen—Sisal, aloe,
(*b*) Sections attached but lumen small—Yucca, jute, mallow.

CHAPTER XXVI

ANALYSIS OF TEXTILE FABRICS AND YARNS

1. Wool and Cotton Fabrics.—In the analysis of finished textile fabrics it must be remembered that besides the fibers there is nearly always present also a certain amount of sizing and finishing materials, mordants and coloring matters, and these must be taken account of in the analysis of the fabric. The finishing materials and coloring matter should be removed as far as possible by boiling a weighed sample of the fabric, first in a 1 percent solution of hydrochloric acid, then in a dilute solution of sodium carbonate (about a $\frac{1}{2}$ percent solution), and finally in water. It is then air-dried and reweighed; the loss will represent finishing materials. A portion of the material is then dried at 100° C., for an hour (or until constant weight is obtained) and weighed; this weight will represent the actual amount of true fiber present in the sample, and the loss will correspond to moisture. Then steep for twelve hours in a mixture of equal parts of sulfuric acid and water, and mix with three volumes of alcohol and water; filter off the dissolved cotton and wash the residue of wool well with alcohol. Dry at 100° C., and weigh; this will give approximately the amount of wool present. By this treatment the wool suffers a loss of about $2\frac{1}{2}$ percent. The following example will illustrate this method:

	Grams.
Sample weighed	3.62
After treatment with acid and alkali	3.17
Finishing materials, etc	0.45
After drying at 100° C	2.77
Loss as water	0.40
Wool left after treating with acid	1.96
Cotton, by difference	0.81

Hence the composition of this sample would be as follows:

	Percent
Finishing materials	12.43
Moisture	11.05
Wool	54.14
Cotton	22.38
	100.00

Another, and perhaps a better, method for determining the relative amounts of wool and cotton in a mixed fabric or yarn, especially when the cotton is present in rather large proportion, is to remove the wool by treatment with a dilute boiling solution of caustic potash. The estimation is carried out in the following manner:

The sample to be tested is treated with hydrochloric acid and sodium carbonate solutions as before, in order to remove finishing materials, and after thorough washing is dried at 100° C. and weighed. This gives the weight of the dry fibers. The weighed sample is then boiled for twenty minutes in a 5 percent solution of caustic potash. It is not advisable to use caustic soda instead of caustic potash, as the results obtained are not quite as satisfactory. The residue is well washed in fresh water, and redried at 100° C. and weighed. The residue consists of cotton, the wool having been dissolved by the caustic potash. If the residue becomes disintegrated and cannot be washed and dried as one piece, it should be collected on a tared filter (one which has been dried at 100° C. and weighed) and well washed with water, then dried at 100° C., and weighed. The tared weight of the filter subtracted from the latter will give the weight of the cotton particles.

In case yarns are to be analysed, the preliminary treatment should consist of a thorough scouring with soap. After drying in the air, the loss in weight should be recorded as grease and miscellaneous dirt. On then drying at 100° C. to constant weight, the loss will represent moisture, and the residue dry fiber. This is then analysed as in the manner above described.

Examples:

(*a*) Analysis of a cloth sample:

	Grams.
Weight of sample	5.42
After treatment with acid and alkali	5.10
Finishing materials, etc	0.32
After drying at 100° C	4.26
Loss as water	0.84
Cotton left after boiling with caustic alkali	2.82
Wool, by difference	1.44

Hence the composition of this sample would be:

	Percent.
Finishing materials	5.98
Moisture	15.50
Cotton	52.03
Wool	26.49
	100.00

Since the cotton itself suffers a slight loss on boiling with caustic potash, it is customary, as a correction, to add to the cotton found 3 percent of its weight,[1] and to subtract a corresponding amount from that of the wool. On applying this correction the result of the above analysis would become:

	Percent.
Finishing materials	5.98
Moisture	15.50
Cotton	53.59
Wool	24.93
	100.00

Figured on the weight of the dry fiber, the relative amounts of the two fibers in the above samples would be:

	Percent.
Cotton	68.2
Wool	31.8
	100.0

Since, however, in making mixes, the dry weights of the fibers are not taken, we may assume the weight to include the normal amount of moisture held by each fiber. As the normal amount of moisture for cotton is about 8 percent, and for wool about 16 percent, we may approximate very closely to the true composition of this sample by adding to the dry weights of the fibers their respective amounts of moisture, the relative amounts of cotton and wool then become:

	Grams.
Weight of cotton found	2.82
Add 3 percent correction	0.08
	2.90

[1] Some writers state that 5 percent should be added to the cotton but the author has found that the cotton will not lose, as a rule, more than 3 percent. The Conditioning House at Aachen has confirmed his results in this matter and give 3.5 percent as the figure for the loss in the weight of the cotton.

This represents 92 percent of air-dry cotton.

	Grams.
Hence air-dry cotton would be	3.15
Weight of wool found	1.44
Subtract correction for cotton	0.08
	1.36

This represents 84 percent of air-dry wool.

	Grams.
Hence air-dry wool would be	1.62

Therefore the relative amounts of cotton and wool on this basis would be:

	Percent.
Cotton	66.0
Wool	34.0

(*b*) Analysis of a yarn:

	Grams.
Weight of sample	5.65
Scoured in soap, washed and air-dried	4.97
Grease, etc.	0.68
Dried at 100° C.	4.32
Loss as moisture	0.65
Weight of filter-paper dried at 100° C.	1.16
Weight of filter and residue of cotton dried at 100° C.	3.66
Weight of dry cotton	2.50
Add 3 percent correction	2.57
Correct for moisture at 8 percent	2.68
Weight of dry wool by difference (with correction)	1.75
Correct for moisture at 16 percent	2.08

Hence the composition of this yarn may be expressed as:

	Percent.
Grease, etc.	12.00
Moisture	11.50
Cotton	45.40
Wool	31.10
	100.00

And the relative proportion of the two fibers would be as follows:

	Dry at 100° C.	Air-dry.
Cotton	59.5	56.3
Wool	40.5	43.7
		100.0

The following scheme for the analysis of a fabric containing wool and cotton is given by Herzfeld:[1]

(*a*) *Estimation of moisture.*—Five grams of the fabric are dried at 100° C. until the weight is constant. The loss indicates the amount of moisture present.

(*b*) *Estimation of cotton.*—Five grams of the fabric are boiled for one-quarter hour with 100 cc. of a 0.1 percent solution of caustic soda, then washed with water and treated with lukewarm 10 percent caustic potash solution, until the wool fibers are completely dissolved, if necessary the liquid being raised to the boiling-point. The residue is washed with water, then treated for one-quarter hour with dilute hydrochloric acid, then washed again with water, boiled for one-quarter hour with distilled water, washed with alcohol and ether, and finally dried at 100° C. until constant weight is obtained. The residue is cotton. The object of washing with dilute hydrochloric acid is to neutralise the excess of caustic alkali in the fiber, so that it may be more readily removed, as caustic alkali remains in the fiber very tenaciously.

(*c*) *Estimation of wool.*—Five grams of the cloth are boiled with 100 cc. of a dilute solution of soda-ash for one-quarter hour, washed with water, and steeped for two hours in sulfuric acid of 58° Bé.[2] then washed with water, and boiled for one-quarter hour with water, and finally washed with alcohol and ether, and dried at 100° C., until constant weight is obtained. The residue is wool.

(*d*) *Dressing and dye* are found by difference.

The method of analysis given by Kapff[3] is as follows: Weigh out 5 grams of the sample (air-dry), scour with a luke-warm (140° F.) ammoniacal solution of soap to remove impurities and finishing materials (in the case of heavily finished goods it may be necessary to use also a hot 2 percent solution of hydrochloric acid), then wash well and air-dry overnight. The difference in weight (diminished by 2 percent if boiled with hydrochloric acid, as loss to the fiber) corresponds to impurities and finish. The sample is now boiled for fifteen minutes in a solution of 5 grams

[1] *Yarns and Textile Fabrics*, p. 145.

[2] Acid of this strength is somewhat too strong, as it will decompose the wool to a considerable extent. It is not safe to employ sulfuric acid of greater strength than 1 part of acid to 1 part of water by volume.

[3] *Textil-Zeit.*, 1900, p. 462.

of caustic soda in 250 cc. of water (3° to 4° Bé.), which will cause all the wool to be dissolved. The residue of cotton is thrown on a fine copper gauze and washed, first with water, and then with dilute hydrochloric acid and finally with water again, after which it is allowed to dry in the air for twelve hours and reweighed. To this weight add 3.5 percent of its amount as a correction for loss to the cotton on boiling with the alkali, and this figure will then represent the weight of cotton present.

When a rough, approximate analysis of a wool-cotton fabric is desired, it will be sufficient only to weigh the sample, boil for fifteen minutes in a 5 percent solution of caustic potash, wash well in acidulated water, then in fresh water, and dry in the air. On reweighing, the amount of cotton will be ascertained, while the loss in weight will represent the amount of wool. Results attained by this process are usually sufficiently accurate to give one a practical idea of the approximate relative amounts of wool and cotton present in a sample of mixed goods.

Another method for the separation of wool from cotton in their quantitative estimation is treatment of the mixed fibers with an ammoniacal solution of copper oxide, whereby the cotton is dissolved; and after washing and drying, the residue of wool is weighed. This method, however, is not very satisfactory, as it is difficult, in the first place, to obtain a complete and thorough solution of the cotton; and in the second place, the wool will be considerably affected by this treatment and more or less decomposed. Consequently the results obtained by this method are not very accurate, and it cannot be recommended.

For the analysis of wool and cotton fabrics or yarns where the amount of wool is relatively quite small, Heerman recommends the following method in which the wool is separated and estimated by direct weighing: The method is based on the solubility of cotton and the insolubility of wool in cold sulfuric acid of a certain concentration. In a series of experiments it was found that an acid containing 80 percent of H_2SO_4 is the most suitable for the purpose. Sulfuric acid of this strength dissolves cotton completely in from two to three hours. Pure wool treated for six hours with 80 percent sulfuric acid lost only 1.5 percent in weight, and was microscopically unchanged. The estimation is carried out in the following way: 5 to 10 grams of the sample is thoroughly extracted, first with ether, and then with 96 percent alcohol, and then treated in a stoppered flask with from 10 to 20 times the weight of 80 percent sulfuric acid. The mixture is allowed to stand for six hours, and is well shaken at intervals. By this time the cotton is completely dissolved. The liquid is diluted with cold water, and any wool which is present is collected on a fine copper sieve, washed well, finally with very dilute ammonia, dried, and weighed. The drying may be done either at about 225° F., or else at the ordinary temperature in the air. In the latter case the wool will contain approxi

mately 17 percent of moisture, this being the normal amount for the air-dried fiber.

It has also been suggested to use the percentage of nitrogen as a basis for the analysis of wool-cotton fabrics, relying on the assumption that the amount of nitrogen in wool is sufficiently constant to make this factor an accurate measure of the amount of wool present.[1] The analysis of a large number of samples of wool fabrics (yarns and cloth) gave a nitrogen content by the Kjeldahl method of between 13.81 and 14.23 percent, or a mean of 14.00 percent. The analysis may be conducted, therefore, by first removing finishing materials, dirt, and grease by scouring with soap, drying at room temperature, weighing out about 5 grams of the sample thus prepared, determining the percentage of nitrogen by the Kjeldahl method, and calculating the amount present as follows:

$$\text{Percentage of wool} = \frac{100 \times \text{percent nitrogen found}}{14}.$$

The nitrogen present in cotton is so small (only 0.25 percent in raw cotton) that its amount may be disregarded. Even the amount of nitrogen present in the dye on colored samples is usually so small as to be negligible.

2. Analysis of Wool and Staple Fiber Mixtures.—Staple fiber is a rather recently introduced textile material and consists of short lengths of artificial silk spun into a yarn. It is largely used in connection with wool for the preparation of novelty yarns and fabrics. The fiber consists of cellulose, but on account of its sensitiveness to alkalies mixtures of staple fiber with wool cannot be analysed in the same general manner as cotton and wool mixtures. Krais and Biltz [2] give the following method of analysis: Mixtures of wool and staple fiber cannot be estimated in the same manner as mixtures of wool and cotton by boiling with caustic soda solution and weighing the residue of vegetable fiber, as staple fiber from cuprate silk loses 6 percent while staple fiber from viscose silk loses 7 percent by the alkaline treatment. Carbonising with acid also does not give good results. The staple fiber, on the other hand, is rapidly and completely removed from the mixture by treatment with an ammoniacal copper solution. The solution is prepared by half filling a stoppered flask with copper turnings and adding ammonia (specific gravity 0.905) until nearly full, then air is blown in with occasional shaking for several days. The resultant deep blue solution contains 1 percent of copper oxide and should have a specific gravity of 0.925. About 0.2 to 0.5 gram of the sample is weighed into a porcelain dish, covered with 10 cc. of the copper solution, and stirred from time to time during half an hour. The solution is decanted and the residue treated for a further half hour with fresh

[1] Ruszkowky and Schmidt, *Chem. Zeit.*, 1909, p. 949.

[2] *Textile Forschung*, 1920, p. 24.

copper solution, filtered, washed with strong ammonia water, followed by 10 percent ammonia water and finally by water. The residue is treated for one hour with 10 percent hydrochloric acid, washed with cold and warm water until neutral, pressed between filter paper and dried at 110° C. Wool treated in this manner shows a loss in weight of only 0.42 percent.

3. Wool and Silk.—Silk is soluble in strong hydrochloric acid, whereas wool is not soluble in this reagent to any extent. Hence this method may be utilised for the quantitative estimation of the two fibers when occurring together. The sample is first treated with acid and alkali in the manner already described in order to remove foreign material other than actual fiber. It is then dried and weighed; then immersed in cold concentrated hydrochloric acid (about 40 percent strength). The silk dissolves almost immediately. The residue is collected, washed thoroughly, dried again, and weighed. The loss in weight represents silk, while the weight of the residue represents wool.

Another method, and one which is very satisfactory, is to dissolve the silk by treatment with an ammoniacal solution of nickel oxide, in which reagent the silk is very readily soluble even in the cold. It only requires a treatment of about two minutes to completely dissolve the silk in most silk fabrics other than plush. Richardson [1] found that by this treatment cotton lost only 0.45 percent in weight and wool only 0.33 percent. As silk in plush goods and similar fabrics is much more difficult to dissolve, it is recommended to boil such material with the nickel solution for ten minutes under a reflux condenser. By this treatment cotton will lose only 0.8 percent in weight. The nickel solution is best prepared by dissolving 25 grams of crystallised nickel sulfate in 80 cc. of water; add 36 cc. of a 20 percent solution of caustic soda, carefully neutralising any excess of alkali with dilute sulfuric acid. The precipitate of nickel hydroxide is then dissolved in 125 cc. of strong ammonia, and the solution diluted to 250 cc. with water.

Instead of the above reagent, a boiling solution of basic zinc chloride may be employed for the purpose of dissolving the silk. This latter solution is obtained by heating together 1000 parts of zinc chloride, 850 parts of water, and 40 parts of zinc oxide until complete solution is effected. Richardson recommends that the sample to be examined should be plunged two or three times into the boiling solution of zinc chloride, care being taken that the total time of immersion does not exceed one minute. The zinc chloride solution should be sufficiently basic and concentrated in order to obtain good results. Under the best conditions, cotton loses about 0.5 percent in weight, and wool from 1.5 to 2.0 percent.

The chief difficulty attached to the use of the zinc chloride solution is that it requires a long and tedious washing to remove all of the zinc salt

[1] *Journ. Soc. Chem. Ind.*, 1893, p. 430.

from the residual fibers. It is best to wash with water acidulated with hydrochloric or acetic acid.

Darling recommends the use of ammonio-nickel-oxycarbonate as a reagent for the determination of silk in cotton-silk or cotton-wool-silk mixtures. The reagent is prepared by precipitating the nickel oxycarbonate from a solution of nickel sulfate (5 grams in 100 cc. of water) with a saturated solution of sodium carbonate. This is well shaken, filtered and washed with water until free from sulfate (tested with a solution of barium chloride). The salt is allowed to dry by exposure to the air, powdered, and bottled. The reagent is prepared by dissolving the salt in 20 percent ammonium hydroxide. The method of determining the silk in the sample is as follows: The weighed sample (about 1 gram) is immersed in 25 cc. of the reagent and well stirred. After allowing to stand about ten minutes in a warm place it is removed, rinsed, dried, and weighed. The loss is due to the dissolving of the silk in the reagent. The best method of washing the sample is to place it in a Gooch crucible with a layer of glass wool in the bottom. The glass wool is readily washed free from the reagent and does not hold it as will asbestos. Another advantage of glass wool over asbestos is that there are no small particles to adhere to the sample.

Another method recommended for the analysis of wool-silk fabrics is as follows:[1] The sample is treated with dilute hydrochloric acid, then soda ash to remove finish, dried, and weighed. Concentrated hydrochloric acid (40 percent) is used at 50° C. to dissolve out the silk. The wool is washed, dried, and weighed. Another method is to boil the sample for five minutes in turbid ammonia-nickel hydroxide solution, remove the wool, wash with water, and with hydrochloric acid to remove the nickel, then dry and weigh. Boiling basic zinc chloride dissolves silk rapidly (wool more slowly). The wool needs washing from zinc salts with dilute (1 percent) hydrochloric acid and water. Silk in a fiber may be identified under the microscope.

4. Silk and Cotton.—The methods given above for separating silk from wool may also be used for the separation and quantitative determination of silk in fabrics containing this fiber in conjunction with cotton.

Another method for separating silk from cotton is by the use of an alkaline solution of copper and glycerol, which serves as an excellent solvent for the silk. The reagent is prepared as follows: Dissolve 16 grams of copper sulfate in 150 cc. of water, with the addition of 10 grams of glycerol; then gradually add a solution of caustic soda until the precipitate of copper hydrate which is at first formed just redissolves. This solution readily dissolves silk, but is said not to affect either wool or the vegetable fibers. Richardson, however, has found that cotton heated with this solution for

[1] *Possell's Textile Jour.*

twenty minutes (the time necessary to dissolve silk in plush) lost from 1 to 1.5 percent in weight and became friable and dusty on drying; while woolen fabrics lost from 9 to 16 percent in weight. Hence the reagent would be useless in the analysis of fabrics containing wool.

5. Wool, Cotton, and Silk.—Samples of shoddy frequently contain all three of these fibers present in greater or lesser amount, and often it is desirable to know at least the approximate amounts of each fiber in the mixture. A method of procedure recommended is the following: A weighed sample of the material is boiled for thirty minutes in a 1 percent solution of hydrochloric acid, washed, and then boiled for thirty minutes in a 0.05 percent solution of soda-ash. This preliminary operation is similar to that above described in the preceding analyses, and is for the purpose of freeing the fibers as far as possible from extraneous foreign matter. After thorough washing and air-drying, the weight of the sample is again taken, and the loss will represent *miscellaneous foreign matter.* The sample is then dried at 105° C. to constant weight; the loss in weight will represent *moisture.* The sample is then divided into two weighed portions; the first is treated for five minutes with a boiling solution of basic zinc chloride prepared as above described, washed thoroughly with acidulated water, then with fresh water, and dried at 100° C. again. The loss in weight will represent the amount of silk present. The second portion of the sample is boiled for ten minutes in a 5 percent solution of caustic potash; washed thoroughly, dried at 100° C. and weighed. This weight, with a correction of 5 percent added to it, will represent the amount of cotton present. The amount of wool is obtained by taking the difference between the total weight of the combined fibers and the sum of the weights of the silk and cotton.

Example:

	Grams.
Sample of loose shoddy weighed	5.06
Treated with acid and alkali, and air dried	4.23
Loss as foreign matter	0.83
Dried at 100° C.	3.62
Loss as moisture	0.61

Divided into two portions:

	Grams.
(*a*) weighed	1.95
(*b*) weighed	1.67
(*a*) treated with zinc chloride	1.73
Loss as silk	0.22
(*b*) treated with caustic potash, residue as cotton	0.34
Loss as wool	1.33

Hence the composition of this sample on the basis of dry fiber would be:

	Percent.
Silk	11.3
Cotton	21.5
Wool	67.2
	100.0

Von Remont gives the following method for analysing fabrics containing a mixture of silk wool, and cotton. Four quantities (*A*, *B*, *C*, *D*) of 2 grams each of the air-dried material are weighed out. Portion *A* is kept aside, and each of the other three is boiled for fifteen minutes in 200 cc. of water containing 3 percent of hydrochloric acid. The liquid is decanted, and the boiling repeated with more dilute acid. This treatment removes the size and the major portion of the coloring matter. Cotton is nearly always decolorised quite rapidly, wool not so readily, and silk but imperfectly, especially with black-dyed fabrics. The samples should be well washed and squeezed in order to remove the acid liquor. Portion *B* is set aside. Portions *C* and *D* are then placed for two minutes in a boiling solution of basic zinc chloride (of 1.72 specific gravity, and prepared as above described), which dissolves any silk present. They are then washed with water containing 1 percent of hydrochloric acid, and again with pure water, until the washings no longer show the presence of zinc. Portion *C* is squeezed and set aside. Portion *D* is boiled gently for fifteen minutes with 60 to 80 cc. of caustic soda solution (1.02 specific gravity) in order to remove any wool. The sample is then carefully washed with water. The four portions are next dried for an hour at 100° C., and then left exposed to the air for ten hours in order to allow them to absorb the normal amount of hygroscopic moisture. The four samples are then weighed, and calling *a*, *b*, *c*, and *d* their respective weights, we shall have:

$a - b =$ dye and finishing material;
$b - c =$ silk;
$c - d =$ wool;
$d =$ cotton (or vegetable fiber).

This method is open to objections, as the plan of using air-dried material then drying at 100° C., and subsequently exposing to the air again before reweighing, is liable to give very erroneous results. Richardson recommends that the samples should be thoroughly dried at 100° C. before being weighed out, and the treated portions should subsequently be dried at the same temperature before weighing. In order to prevent the sample from absorbing moisture during weighing, it is best to use a weighing-bottle for holding the dried fiber. The sample before drying is placed in a

weighing-bottle (the weight of which has been ascertained previously) and heated in an air-oven at 100° C. for the time specified, during which the cover of the weighing-bottle is removed. After the drying process is completed the stopper is replaced in the weighing-bottle; the latter is taken from the oven, allowed to cool, and is then weighed. The difference between this weight and the weight of the empty bottle will give the amount of dry fiber.

Treatment with a boiling solution of 3 percent hydrochloric acid for the purpose of removing finishing materials is rather too severe, as the acid will act on the wool and the cotton, sometimes causing considerable error. Boiling with a 1 percent solution of acid for ten minutes is to be preferred.

The following is given as a practical method to determine if shoddy contains cotton and silk fibers: Boil 10 grams of the shoddy to be tested for one hour in 400 cc. of water containing 0.8 gram of alum, 0.3 gram of tartar, 1 cc. of hydrochloric acid, 0.1 gram of chrome, and 0.05 gram of bluestone. Rinse and dye with 0.3 gram of logwood extract. Rinse and dry. The undyed fibers are then picked out and examined; cotton will remain white, while silk will be colored a dingy red.

The analysis of heavy pile fabrics containing a mixture of fibers is especially difficult unless the fabric is disintegrated. In the analysis of plush for the amount of silk present, Richardson suggests treating the sample with a boiling solution of basic zinc chloride in the manner previously described; but when silk is to be determined in light fabrics (especially in the presence of wool) it is best to treat the sample for one to three minutes with a cold solution of ammoniacal nickel oxide. He gives the following comparison of results in the analysis of a sample of plush, using the three different methods for dissolving the silk:

	By Solution of Ammoniacal Nickel Oxide.	By Solution of Basic Zinc Chloride.	By Copper-glycerol Reagent.
Moisture and finish	11.34	11.00	10.04
Silk	45.60	45.00	47.06
Cotton	43.60	44.00	42.90

Samples of plush with hard cotton backs may best be analysed by successive treatment with acid and copper-glycerol reagent. On other cotton material, however, this method is not suitable; nor is it to be used in the presence of wool, as this fiber is considerably dissolved by the copper-glycerol reagent.

The following table by Richardson shows a comparison of the three methods employed for dissolving silk:

Fiber.	Actually Present.	Percentage Obtained by		
		Ammoniacal Nickel Oxide.	Basic Zinc Chloride.	Copper-glycerol Reagent
Silk	5.84	5.92	5.52	18.80
Wool	76.31	76.58	80.08	64.05
Cotton	17.85	17.50	14.40	17.15

The ammoniacal nickel oxide solution appears to give the best results; hence, in analysing a sample containing silk, wool, and cotton, it is best first to remove the silk by means of this reagent. The insoluble residue left after this treatment is boiled with a 1 percent solution of hydrochloric acid, washed well in fresh water, and then boiled for five to ten minutes in a 2 percent solution of caustic potash, which is sufficient to remove completely the wool without materially affecting the cotton.

From experiments conducted by the author's students [1] the following comparative results have been obtained in the analysis of textile materials by the different methods suggested.

(*a*) Analysis of wool-cotton mixture:

Fiber.	Dissolving Wool by Caustic Potash.		Dissolving Cotton by Sulfuric Acid.	
	Theoretical.	Found	Theoretical.	Found.
Cotton	56.7	55.2	63.7	64.2
Wool	43.3	44.8	36.3	35.8

(*b*) Analysis of wool-silk mixture:

Fiber.	With Hydrochloric Acid.		With Ammoniacal Nickel Oxide.		With Basic Zinc Chloride.	
	Theoretical.	Found.	Theoretical.	Found.	Theoretical.	Found.
Wool	76.6	76.24	78.5	77.3	81.7	71.5
Silk	23.4	23.76	21.5	22.7	18.3	28.5

[1] Collingwood, *Textile World Record*, vol. 29, pp. 874, 1193.

(*c*) Analysis of cotton-silk mixture:

Fiber.	With Hydrochloric Acid.		With Ammoniacal Nickel Oxide.		With Basic Zinc Chloride.	
	Theoretical.	Found.	Theoretical.	Found.	Theoretical.	Found.
Cotton	70	67.5	65.12	64.42	71.11	70.13
Silk	30	32.5	34.88	35.52	28.89	29.87

(*d*) Analysis of wool-cotton-silk mixture:

Fiber.	Silk by Ammoniacal Nickel Oxide; Wool by Caustic Potash.		Silk by Ammoniacal Nickel Oxide; Cotton by Sulfuric Acid.	
	Theoretical.	Found.	Theoretical.	Found.
Wool	41.2	42.1	41.0	39.0
Cotton	42.7	41.6	48.1	49.2
Silk	16.1	17.3	10.9	11.8

Fiber.	Silk by Hydrochloric Acid; Wool by Caustic Potash.		Silk by Hydrochloric Acid; Cotton by Sulfuric Acid.	
	Theoretical.	Found.	Theoretical.	Found.
Wool	38.9	39.4	28.6	24.0
Cotton	42.2	38.0	47.7	48.8
Silk	18.9	22.6	23.7	27.2

Fiber.	Silk by Basic Zinc Chloride; Wool by Caustic Potash.		Silk by Basic Zinc Chloride; Cotton by Sulfuric Acid.	
	Theoretical.	Found.	Theoretical.	Found.
Wool	59.0	57.5	63.5	61.6
Cotton	26.3	24.4	19.7	20.0
Silk	14.7	18.1	16.8	18.4

From a consideration of these results it would appear that in the analysis of wool-cotton mixtures the rapidity with which the caustic potash dissolves the wool gives this method a slight preference over the somewhat slower one of destroying the cotton by treatment with sulfuric acid. In the analysis of wool-silk materials the treatment with hydrochloric acid is slightly better than by the use of ammoniacal nickel oxide. The latter reagent, however, is the better to use for dissolving the silk from cotton-silk mixtures, as the cotton is too readily attacked by the concentrated hydrochloric acid. In the analysis of wool-cotton-silk mixtures the only proper reagent to employ for dissolving the silk is the solution of ammoniacal nickel oxide. Though the use of this reagent is rather slow compared with the acid, it is thorough, and its action on the other two fibers is but slight.

The following table shows the corrections to be applied in the calculations of results, by reason of the action of the different reagents on the fiber which is not to be dissolved:

	Percent.
(1) *Wool-cotton mixtures:*	
(*a*) Wool dissolved by caustic potash; correction for loss of cotton	3.0
(*b*) Cotton dissolved by sulfuric acid; correction for loss of wool.	2.5
(2) *Wool-silk mixtures:*	
(*a*) Silk dissolved by hydrochloric acid; correction for loss of wool	0.5
(*b*) Silk dissolved by ammoniacal nickel oxide; correction for loss of wool	1.5
(*c*) Silk dissolved by basic zinc chloride; correction for loss of wool	2.0
(3) *Cotton-silk mixtures:*	
(*a*) Silk dissolved by hydrochloric acid; correction for loss of cotton	4.0
(*b*) Silk dissolved by ammoniacal nickel oxide; correction for loss of cotton	1.0
(*c*) Silk dissolved by basic zinc chloride; correction for loss of cotton	1 5

Allen[1] also recommends the ammoniacal nickel solution for use in dissolving silk from a mixture of fibers. His method of analysing a textile sample is as follows: The yarn or fabric is cut up very fine with a pair of scissors, and thoroughly dried at 100° C. One gram of the material thus prepared is treated with 40 cc. of the cold ammoniacal nickel oxide solution for two minutes. The liquid is then filtered, and the residue, consisting of wool and cotton, is digested for two or three minutes in a boiling solution of 1 percent hydrochloric acid. It is then washed free from acid, dried at 100° C., and weighed. To separate the wool from the cotton the residue is boiled with about 50 cc. of a 1 percent solution of caustic potash for ten minutes, and the solution filtered. The residue,

[1] *Commer. Org. Anal.*, vol. 4, p. 523.

consisting of cotton, is washed free from alkali, dried at 100° C., and weighed.

To remove gum and weighting materials from goods containing silk, Richardson recommends treatment of the sample with a cold 2 percent solution of caustic potash; this not only removes any gum, but also decomposes any Prussian Blue that may be present (as a bottom under the black dye), so that the iron may be more easily removed by subsequent treatment with a 1 percent solution of hydrochloric acid. Metallic mordants, however, are difficult to remove in this manner, and at best they dissolve only imperfectly; it is best to calculate their amounts from the quantity of ash left after the ignition of the sample.

Oily matter (and also certain dyes) may be best removed by boiling successively with methylated spirits and ether. By evaporation of the solution so obtained the amount of oil and fat may be directly determined.

Höhnel recommends the use of a semi-saturated solution of chromic acid for the quantitative separation of mixtures containing wool, cotton, flax, true silk, and tussah silk. On boiling such a mixture of fibers in this solution for one minute, the wool and true silk will be completely dissolved leaving as a residue the cotton, flax, and tussah silk.

Other methods given by Höhnel for the quantitative analysis of fabrics containing mixtures of the fibers mentioned above are as follows:

(*a*) Any true silk is first removed by boiling for half a minute in concentrated hydrochloric acid; tussah silk is next removed by a longer boiling in the acid (three minutes); the residue, consisting of wool and vegetable fibers, is further separated in the usual manner by boiling in caustic potash solution.

(*b*) The fabric is first boiled in caustic potash solution, which dissolves the wool and the true silk, and leaves as a residue (*A*) tussah silk and vegetable fiber. A second sample is boiled for three minutes with concentrated hydrochloric acid, which dissolves both varieties of silk and leaves as a residue (*B*) wool and vegetable fiber. Residue *A* is then boiled three minutes with concentrated hydrochloric acid, which dissolves the tussah silk and leaves the cotton as a final residue. By subtracting this amount from residue *B* the amount of wool is obtained.

(*c*) A sample of the fabric is boiled for one minute in a semi-saturated solution of chromic acid, which dissolves the true silk and the wool, leaving as a residue the tussah silk and vegetable fiber. From this residue the tussah silk is removed by boiling for three minutes in concentrated hydrochloric acid, leaving the vegetable fiber as a final residue. A second sample is boiled for three minutes in concentrated hydrochloric acid, which dissolves the silks and leaves the wool and vegetable fiber as a residue. From this the amount of wool can be obtained either by boiling in caustic potash solution, or by subtracting the cotton previously estimated. Finally, the amount of true silk may be found by subtracting the sum of the other constituents from the total in the original sample.

6. Distinction between Cotton and Linen.—As it is often desirable to discriminate between these two fibers, the following tests, as suggested by various authorities, are given. These chemical tests, however, are

only satisfactory when the linen is in an unbleached condition. Bleached linen will show practically no difference from cotton in the tests, as in both cases the cellulose of the two fibers is identical in its chemical behavior. The most satisfactory test to distinguish between cotton and linen is to submit the fibers to a microscopical examination. The chief microscopical distinctions between cotton and linen fibers are in the twist and smoothness of the cotton fiber, the presence of the cuticle, the blunt point, the absence of joints, and the irregular granulations and striations on the fibers.

(1) The fiber is burned:
Cotton—burned end tufted.
Linen—burned end rounded.

(2) The fiber is immersed in concentrated sulfuric acid for two minutes, washed well with water, then with dilute ammonia water, and dried (Kindt and Lehnert):
Cotton—forms a gelatinous mass soluble in water.
Linen—the fiber is unaltered.

(3) The fiber is treated with an alcoholic solution of madder for fifteen minutes and then dried between two sheets of blotting paper:
Cotton—becomes bright yellow in color.
Linen—becomes dull orange yellow in color.

(4) The fiber is treated with an alcoholic solution of cochineal for fifteen minutes:
Cotton—becomes bright red in color.
Linen—becomes violet red in color.

(5) The fiber is immersed in olive oil or glycerol, after having been boiled in water and well dried.
Cotton—remains opaque and white.
Linen—becomes translucent by reason of the oil rising by capillary action between the individual filaments of the fibers.

In this test the fibers after saturation with oil should be well pressed between white filter-paper to remove all excess of the liquid. This test is of doubtful value and is not to be recommended as at all decisive. According to Frankenstein this test is useful for distinguishing between cotton and linen cloth; the cloth samples are saturated with the oil and placed between glass plates and observed with a magnifying glass; the linen becomes translucent and appears light in transmitted light and dark in reflected light; the opposite being the case with cotton.

(6) The fiber is treated with an alcoholic solution of rosolic acid, and then with a concentrated caustic soda solution:
Cotton—remains colorless.
Linen—becomes rose red in color.

(7) The fiber is treated with iodine and sulfuric acid solutions:
Cotton—becomes pure blue in color.
Linen—gives a dull blue color. This test is satisfactory only on unbleached linen.

(8) A small portion of the sample is boiled in a solution of equal parts of water and caustic potash; at the end of two minutes the sample is raised with a glass rod, and placed between several thicknesses of filter-paper to remove the excess of water:
Cotton—remains white or is a pale, clear yellow in color.
Linen—becomes dark yellow in color. This test is adapted only for white goods.

(9) Kuhlmann recommends the use of a cold concentrated solution of caustic

potash (specific gravity 1.6). This causes unbleached *cotton* to shrink and curl up, and to become gray or dirty white in color; whereas unbleached *linen* shrinks more than cotton, and acquires a yellowish orange color.

(10) The fibers are boiled in water, dried, immersed in a saturated solution of sugar and common salt, and dried. The separate threads are then ignited:

Cotton—leaves a black-colored ash.

Linen—leaves a gray-colored ash.

(11) The fibers are treated with a 1 percent alcoholic solution of Magenta (Fuchsine), and then washed with a weak solution of ammonia (see Fig. 398):

Cotton—at first stained a rose color which is washed out by the ammonia.

Linen—the rose color is permanent.

(12) Herzog [1] recommends the following test to distinguish between cotton and linen in a woven fabric: A small piece of the cloth is cut out and the edges are fringed. The sample is then steeped for a few minutes in a lukewarm alcoholic solution of Cyanine; it is then washed with water and treated with dilute sulfuric acid. By this treatment the *cotton* is completely decolorised, while *linen* retains a distinct blue coloration. To make the blue color still more distinct, the material should be washed free from acid and placed in ammonia. The coloration is said to be due to the presence on the linen fiber of fragments of epidermis which readily absorbs the dyestuff.

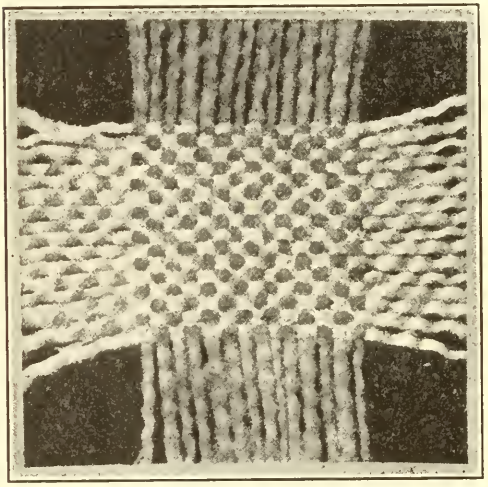


Fig. 398.—Appearance of Cotton-linen Fabric with Fuchsine Test; Linen = Red Vertical Threads; Cotton = White Horizontal Threads.

(13) In Behren's method of distinguishing cotton from linen in fabrics, the cloth is first carefully boiled in water and then in a dilute solution of soda ash to remove finishing compounds. The sample is then heated in a dilute solution of Methylene Blue until a rather dark shade of blue is obtained. The samples are then washed with water until the *cotton* has become almost colorless and has acquired a greenish tone. Under these conditions *linen* will remain a dark blue color. Zetzsche recommends this test as quite satisfactory. Bismarck Brown or Safranine may also be used for this test. The method, however, is not suited for bleached fabrics.

(14) Herzog also gives the following process: steep the sample for ten minutes in a 10 percent solution of copper sulfate, wash well and then steep in a 10 percent solution of potassium ferrocyanide; *linen* will become colored red, while *cotton* not taking up the copper will remain white. The contrast is made very plain after rinsing by immersing the sample in Canada balsam.

(15) Behrens also recommends the use of Chrysophenine in combination with Safranine as follows: The sample to be tested is first stained in a hot Safranine solution a dark rose color. It is then washed with cold water and placed in a cold solution of Chrysophenine slightly alkaline with soda ash. Under these conditions, flax will

[1] *Zeit. f. Farben und Text. Ind.*, 1905, p. 11.

appear a dull red and cotton yellow. When treated in like fashion wool and silk will be colored a carmine red, jute and Manila hemp a scarlet, and hemp a dull red. The solutions of the dyes are best made up fresh for each test.

To distinguish the nature of threads in fabrics of linen or mixed linen and cotton, R. Dantzer recommends the following commercial tests:

(1) *Test by Tearing.*—The linen threads are much stronger than cotton and if it is as difficult to tear a fabric warp-ways as it is filling-ways, it is fairly certain that the cloth is pure linen. After a little practice in tearing cloths one can distinguish the difference between linen and cotton by the sound of the tear. Linen gives a dull sound, while the sound caused by tearing cotton is sharper. The difference in the appearance of the torn projecting threads is very perceptible. The broken ends of the linen threads (Fig. 399) have a pearly appearance, the fibers are irregular and lustrous, and the ends of the threads are untwisted, the fibers being very rigid. The ends of the cotton threads show a cleaner break (Fig. 400) and the threads are dull in appearance, the fibers being curled instead of straight. (2) *Test by Untwisting the Yarn.*—Many content themselves with drawing out several threads of warp and filling and untwisting and drawing the thread apart so as to expose the fibers to view. The cotton fibers are shorter and tangled together, while the linen fibers are much longer, fairly parallel, and more brilliant and less flexible. (3) *Test by Ink.*—This process consists in dropping a small quantity of black ink on the sample. Figure 401 shows the form of the ink spots on a pure linen fabric, while Fig. 402 shows the form of the spots on a mixed fabric made of linen and cotton. Each spot is approximately the same size as the black circle in the lower corner of Fig. 401. On

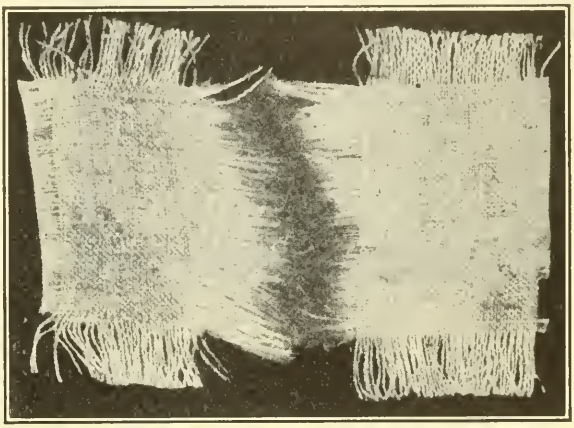


Fig. 399.—Showing Torn Linen Part of Mixed Fabric.

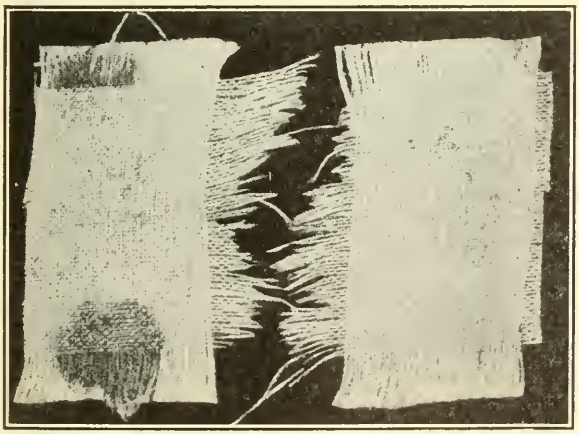


Fig. 400.—Showing Torn Cotton Part of Mixed Fabric.

the pure linen cloth the ink spreads in all directions from the original spot, like a drop of oil on a sheet of paper. On the mixed goods, however, it spreads in the direction of the linen, which is more porous than the cotton.

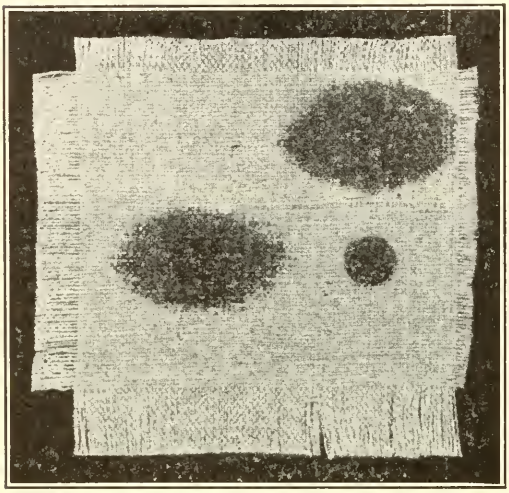


Fig. 401.—Ink Spots on Pure Linen Fabric.

(4) *Test by Burning.*—Linen and cotton have each a cellulose base, but Stockhardt has called attention to a difference between the two materials when they are burned. He claims that the ends of the linen threads after the flame has been extinguished are round and smooth, while the ends of the cotton threads separate more or less in the form of pincers. This distinction is very difficult to make, and Dantzer considers it of little value, and recommends the following: The fabric is ravelled to form a fringe half an inch long of warp and filling. The fringe is then set on fire and the flame acts differently according to the nature of the material. In an all linen fabric the flame burns the cloth both at the top and side, while in a fabric made of cotton warp and linen filling the flame from the linen fringe attacks the cloth, while the cotton fringe burns down to the filling without attacking the cloth. (5) *Test by Oil.*—This method was discovered by Frankenstein. The cloth is first freed from the finishing material by boiling in a weak solution of carbonate of soda. After drying the sample is saturated with oil and placed on a plate with glass. When the air bubbles have disappeared the sample is covered with a smaller piece of glass, the oil is squeezed out, and the cloth is examined by holding it between the observer and the light. The linen fibers become transparent because of the thickness of the cell-walls which gives a refraction equal to that of the oil. By examining it between the light and the observer it appears clear, but when examined in the ordinary manner it is opaque. Owing to the thickness of the cell walls and to the fact that the air is imprisoned in the cells, the cotton fiber is opaque when held before the light and appears clear in other position. (6) Linen and cotton cloths of the same thickness differ materially in weight, linen being about 17 percent heavier.

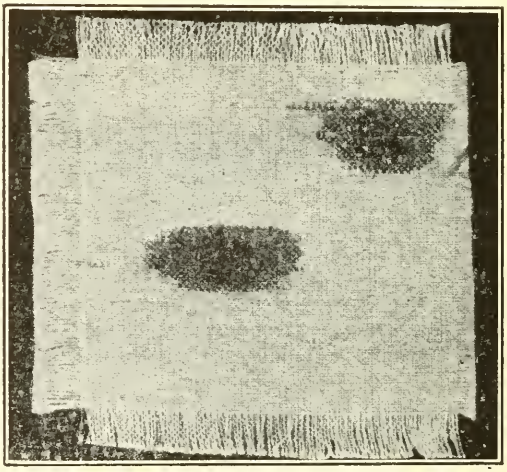


Fig. 402.—Ink Spots on Cotton-linen Fabric.

7. Distinction between New Zealand Flax, Jute, Hemp, and Linen.—The following series of tests is recommended to distinguish between the fibers in question:

(1) The material is immersed in chlorine water for one minute, then spread on a porcelain dish, and several drops of ammonia water added. New Zealand flax and jute become at first bright red in color, which afterward changes to dark brown; linen and hemp acquire a much lighter shade, such as clear brown, orange, or fawn. This method is very good for yarn or unbleached cloth, and is particularly well adapted for testing sail-cloth. French hemp retted in stagnant water is colored a much deeper shade than the same kind of hemp retted in running water; in either case the color is much darker than that acquired by linen. For testing twine this method is said to give excellent results, but in bleached material the difference in the shades produced is not very marked.

(2) To test bleached material, the sample is immersed for one hour, at 36° C., in nitric acid containing nitrous oxide. New Zealand flax assumes a blood red color, while linen or hemp is tinted pale yellow or rose, according to the method by which it was originally retted.

(3) A sample of the material is heated in concentrated hydrochloric acid. Hemp and linen will not become colored, whereas New Zealand flax becomes yellow at a temperature of 30° to 40° C., then becomes red, brown, and finally black.

(4) A sample of the material is treated with a solution of iodic acid. Hemp and linen are not affected, but New Zealand flax acquires a rose-red color.

(5) Jute is distinguished from New Zealand flax by soaking the fibers for two to three minutes in a solution of iodine and then rinsing several times in a 1 percent solution of sulfuric acid to remove excess of iodine. Jute acquires a characteristic reddish brown color; New Zealand flax becomes clear yellow in color; hemp acquires a light yellow color, and linen a blue color. It will be found best to untwist the separate threads previous to this treatment.

(6) Jute may be distinguished from flax and hemp by warming in a solution containing nitric acid and a little potassium chromate, then washing and warming in a dilute solution of soda ash, and washing again. The fibers are then placed on a microscope slide, and when the water has evaporated a drop of glycerol is added. In a short time the characteristic structure of jute will be easily observable, and under the polariscope (with a dark field) the jute fiber will show a uniform blue or yellow color, whereas linen and hemp will show a play of prismatic colors. Also with phloroglucinol and hydrochloric acid, jute is stained an intense red, while linen remains uncolored and hemp acquires only a reddish tint.

8. Distinction between Linen and Hemp.—To distinguish accurately between linen and hemp it is best to have recourse to a microscopical examination. The linen fibers will appear quite regular and with a lumen which is often reduced to a mere line, while the hemp fiber shows a very large lumen, and presents a rather irregular surface. With the iodine-sulfuric reagent hemp gives a green coloration, while linen gives a blue; with nitric acid linen gives no color, while hemp shows a pale yellow coloration. The ends of the linen fibers are pointed, while those of hemp are enlarged and spatula-shaped. Höhnel gives the following distinctions between linen fibers and those of hemp: (1) they do not

form thick bundles, but are more separated from one another; (2) the cross-section does not exhibit an external yellowish layer of rind, when it is treated with iodine and sulfuric acid; (3) it gives the pure cellulose reaction; (4) there is nearly always present a plentiful yellowish content of protoplasm, which the hemp fiber very seldom possess; (5) the fibers end in sharp points.

By a determination of the methyl value it is possible to distinguish chemically between unbleached flax and hemp. The phloroglucinol test cannot be relied on to distinguish between these two fibers.

According to Hanausek [1] linen and hemp may be best distinguished microscopically by the use of a solution of potassium bichromate. The fibers of linen swell up more rapidly than those of hemp, and the dark patches formed on the surface are more pronounced.

The question of the distinction between fibers of flax and hemp is such an important one in practical microscopy that it might be worth while at this point to introduce the remarks of C. Cramer, who published an excellent microscopical study of these two fibers in the *Zürich Polytechnical Journal* for 1881. The length and thickness of the fibers under examination cannot be considered as points of much value, the differences in these measurements being so small as to be practically negligible. Vétillard has already given the thickness of hemp as 50 and flax as 37 microns, but the mean value is about the same for both fibers, which is in support of Cramer's view; the latter found a mean thickness of 46 microns for flax fibers. On the other hand, there is a constant difference in the shape of the fiber ends; and this difference is sufficient to provide a sharp distinction between flax and hemp. This distinction had already been pointed out by Schacht, and latter recognised more definitely by Vétillard. Höhnel claims that each single fiber of hemp can readily be distinguished from flax by an examination of the ends. If the maceration of the material is carried to the proper stage, it is easy to find a large number of ends; usually, however, the maceration is carried too far, hence the fibers become broken at their jointed points, and then it becomes difficult to find the natural ends of the fibers among the broken pieces. The forked ends of hemp are also not of such frequent occurrence. Observations have shown that among 3 to 4 ends, it is almost certain to find a forked one, while with flax nothing similar is to be noticed. The reason why the forked ends are so frequently overlooked is that one of the prongs is usually very much smaller than the other, and often lies above or under the fiber. Consequently in making the examination it is best to twist the fiber around. Hence Höhnel does not agree with Cramer when he attributes no importance to the examination of the ends in uncertain cases. Nor does Höhnel agree with Cramer in working with a magnification of 150

[1] *Zeit. Farb. Ind.*, 1908, p. 105.

to 400; he finds the ends of the fibers with a magnification of 20 to 30, and then notes down the appearance when viewed with a power of 300 to 400. He also dissents from Cramer with respect to the shape of the cross-section, stating that though variations in this will occur, yet one can readily be convinced by observation that the two fibers may be very nicely distinguished by means of their cross-sections. With flax the form of cross-section which predominates by far is the previously described isodiametric, sharp-edged, polygonal form, with the lumen appearing as points; while hemp, on the other hand, has the contrary form; so it is Höhnel's opinion that the shape of the section is a very useful observation. That every individual fiber does not possess the normal form is, as a matter of course, reasonable, and is to be expected.

As to the breadth of the lumen, Höhnel agrees with Cramer in opposition to Wiesner, that it has no special value, as might be deduced from what has already been said in its description. With respect to the stratified form of the wall, which according to most writers is more distinct in the case of hemp than in flax, Höhnel also agrees with Cramer, in the opinion that the difference is too slight to serve as a criterion. Yet there are two conditions to be considered here with which Cramer was not familiar. By the action of Vétillard's reagent on the cross-section, not only in the inner strata are there useful differences to be observed, but also the yellow outer layers are noticeable in the case of hemp, and entirely lacking with flax. With regard to the action of the ordinary reagents for cellulose or woody tissue, it must be said that when no attention is paid to the concentration of the reagents, all possible colors can be obtained with iodine and sulfuric acid, for instance. Therefore the reagents employed must be prepared as definitely stated in the test, and then it is always possible to obtain definite reactions with hemp and flax which will show differences, both with respect to the longitudinal section and the cross-section. Consequently it is Höhnel's opinion that it is quite possible to microscopically distinguish with certainty between pure flax fibers and pure hemp fibers.

The parenchym which surrounds the bast fibers of hemp is rich in star-shaped crystal lumps of calcium oxalate, which is not the case with flax. Furthermore, there are to be found between the fibers, as well as inside of the bast, numerous long-shaped cells filled with a remarkable reddish-brown substance, which is insoluble in the usual solvents (such as caustic potash, alcohol, ether, benzine, sulfuric acid, etc.). These cells of coloring matter (or tannin) are lacking in flax. Finally, the epidermis of hemp is constituted quite differently from that of flax. The epidermis of hemp consists of many small cells, between which only very small openings occur (in 1 cm.^{2} there are probably about 12). These are bounded by only two crescent-shaped end cells, and appear on the epider-

mis as semi-globular warts. There are also to be found on the epidermis of hemp single-celled, bent, and very thick hairs. In the case of flax, the epidermis contains about 3000 fissure openings to the sq. cm., which exhibit just two pairs of crescent-shaped end cells. The fissure openings of linen do not lie on a protuberance, but on the same level with the rest of the epidermal cells. Furthermore, the epidermis of linen possesses scarcely any hairs, and its cells are larger than those of hemp. The cells of the former measure about 140 microns in length and 30 microns in breadth, whereas those of the latter are only 70 microns in length and 20 microns in breadth.

According to Behrens, flax and hemp may be distinguished by the use of Benzopurpurine 10B in combination with Malachite Green. The sample is placed on the object glass with a small granule of Malachite Green and a drop of acetic acid and heated to boiling; after cooling, the excess of dye is soaked up. The sample is washed with hot water and then with cold water. Then the green-colored fiber is steeped in a solution of Benzopurpurine 10B made slightly alkaline with soda ash. Hemp will appear multicolored as an impure mixture of greenish blue and violet, while flax will appear red, though any protoplasmic residues in the lumen will appear green.

Nodder [1] has observed that the striations noticed in the cell-wall of flax and ramie always form left-handed spirals, whereas those in the case of hemp and jute always form right-handed spirals. Further it was found that if a wet fiber is held with the free end toward the observer, flax and ramie are always seen to twist in a clock-wise direction when drying, while hemp and jute always twist in the reverse direction. This distinction forms the basis of a valuable naked-eye test for distinguishing between flax and hemp. The present-day tendency to prepare composite yarns of hemp and linen in various proportions demands a reliable test between these two fibers. Nodder believes that in these twisting properties is to be found a ready means of accurately distinguishing between these two fibers in any stage of their manufacture. To carry out the test the fibers are first well teased out of the material under examination and then soaked for some minutes in warm water. The use of a pair of fine-tipped forceps and a dark background is recommended. As far as possible only single fibers should be examined, and care should be taken to make sure that the twisting is due to drying and not to wetting. To get the best results it is well to hold the thoroughly moistened fiber over a hot plate and observe the direction of the drying twist. The first movement observed in warming a wet fiber is a slight twist in the wet direction, but very soon the steady drying twist sets in. In applying this test to

[1] *Jour. Text. Inst.*, 1922, p. 161.

cotton it was found that the twist may be in either direction, and usually different parts of the same fiber twist in different directions.

9. Distinction between Manila Hemp and Sisal.—In their characteristics these two fibers are very similar and it is quite difficult to distinguish between them. This may be done, however, with more or less accuracy by an observation of the color of the ash, which in the case of Manila hemp is grayish black, while sisal leaves a white ash.

Manila hemp is the principal fiber used for the better grades of cordage and it is frequently adulterated by mixture with the lower grades of the coarse vegetable fibers. As a result of a research conducted by the National Bureau of Standards an excellent and satisfactory test has been devised for distinguishing between Manila hemp and other fibers used to adulterate Manila rope.

The principle of the test is that if a bundle of fibers from a strand of rope is treated in the manner to be described, the Manila fibers turn a russet-brown, and the other fibers turn a cherry-red. There will be slight differences of manipulation according to whether the fiber has been oiled or not; in other words, whether one is testing a sample of fiber before it has been made into rope, or treating a strand of rope itself.

There is required for this test, ether, a solution of bleaching powder, glacial acetic acid and strong ammonia water, together with a vessel of clear water for rinsing purposes. The test is carried out in the following manner: A solution of bleaching powder acidulated with a few drops of glacial acetic acid is first prepared. The different reagents should be contained in suitable vessels standing in a row, namely, ether, bleaching powder solution, water, alcohol and ammonia. Immerse the fibers in the acidulated bleaching powder solution for twenty seconds. The fibers are then rapidly rinsed in water, then in alcohol, and the treated portion is held an inch or two above the surface of the strong ammonia. The Manila fiber turns brown, and all other fibers turn cherry-red, as mentioned before. In most cases the colors remain for a sufficient length of time so that a practiced manipulator can separate them, pulling out the brown fibers or the red ones, as the case may be. The cherry-red color however, is not permanent, but disappears on prolonged exposure to the ammonia fumes. If the fibers are removed as soon as the full color develops, it will last for an hour or so and make quantitative estimation of adulteration easy.

If a sample of rope is being treated, it is best to start with one yarn, and, to remove the oil, ether is poured down the yarn. After waving through the air for a minute or two to expel most of the ether, it is then ready for the course described. There is in some instances such a rapid change of color that one full yarn is too much to handle at one time. It is best, therefore, to start with a few fibers from the yarn. This enables

a rapid separation to be made, and the sample is then ready for the following procedure: After having separated the fibers as described, it is well to take the other end and go through the same course of procedure, except for the following modification: Instead of holding the fibers over the ammonia, it is well to immerse them in the ammonia. If the selection has been properly made, all those fibers characterised as Manila will show the brown color, and all the fibers selected as non-Manila will show the red color. The objection to making just the one test is that the red when so formed tends to degrade too quickly to permit picking out from a bundle of fibers. It is well to make this test as a confirmation.

The bleaching powder solution is made in the following manner. In a large, clean porcelain mortar is placed one part of bleaching powder, and thereto is added, a little at a time, with constant grinding, five parts of water. After a smooth paste has been made, it is transferred to a tall cylinder and allowed to stand away from the light for a few hours until there is a clear solution. This bleaching powder solution should be kept in an amber-colored bottle in the dark, and it will last for several months. When the tests are to be made, it is well to pour an ounce or two of the solution into a tumbler or beaker, and add about one cc. of glacial acetic acid. This acidulation should not be attempted with any other acid than the one specified. Attempts to use hydrochloric acid and the like spoil the test. The solution so made is good for an hour or two, but should be made up fresh each time a series of tests are to be undertaken.

This test has been established on samples of Manila from all provinces, and on samples which have been kept long periods of time, together with fresh samples. Very little experience will be required to establish the satisfactory nature of the tests. There is room for a considerable degree of manipulative skill in the picking out of the fibers, and one who has had practice in microscopic methods should possess the requisite degree of dexterity.

The question sometimes comes up whether a sample of rope is all Manila or not, and when this is the question it is best to practice the modification where the fiber bundle is immersed in the ammonia. This enables one to decide whether he is dealing with mixed fibers or not. If they are all red, then there is no Manila. If they are all brown, then the sample is Manila with no other fibers. If there is a mixture, the course previously described should be followed vigorously. Each time a series of tests is to be undertaken, a clean vessel should be used, and the various solutions poured therein. Ammonia exposed to the air tends to lose strength, alcohol takes water from the air, and the like. The only thing requiring any appreciable length of time is the preparation of the bleaching powder solution, and as stated a solution once made up is good for several months.

When it becomes necessary to estimate the amount of the different fibers in a given mixture, the separations are made as described, after which the Manila on the one hand and the non-Manila on the other are rinsed first with water, then with alcohol, then with ether, and dried at 110° C. After being allowed to cool for an hour or two, they may be weighed and the portion of Manila and non-Manila fibers directly estimated by weight.

It has been ascertained that all varieties of sisal, including true, false, istle, pita and maguey give the red color, as do New Zealand flax, Mauritius hemp, and Sansevieria fiber. Tests on mixtures of known composition have resulted very satisfactorily.

10. Testing for Lignin.—Ligneous matter (derived from woody tissue) may be detected in admixture with other fibers in the following manner:

(1) On exposing the moistened sample to the action of chlorine or bromine, and then treating it with a neutral solution of sodium sulfite, a purple color will be produced.

(2) If the sample be moistened with an aqueous solution of aniline sulfate, an intense yellow color will be produced.

(3) If the sample be moistened with a solution of phloroglucinol of ½ percent strength, and then with hydrochloric acid, an intense violet-red color will be produced. Solutions of resorcinol, orcinol, and pyrocatechol act in a similar manner.

(4) Woody fiber when boiled in a solution of stannic chloride containing a few drops of pyrogallol gives a fine purple color, which is easily seen under a magnifying-glass.

(5) If the sample is treated with a mixture of equal parts of semi-normal ferric chloride and semi-normal ferric ferricyanide solutions, a blue color is formed the intensity of which will indicate the amount of lignification. The reagents must not be used in higher concentrations, as then even pure cotton cellulose will be stained a faint blue.

In testing for lignin the best results are obtained by Cross and Bevan's method. The moist fibers are placed in a suction funnel, chlorine is passed over them and then sulfurous acid gas is drawn down through the tube by suction. The fibers are then washed with water, and afterward with a 2 percent solution of sodium sulfate. The yellow coloration produced by the action of the chlorine, and also the red which appears after the addition of sodium sulfate are very distinct. Cotton, oxycellulose, and hydrocellulose are not colored, but lignified fibers are all colored more or less according to their content of lignin.

Another sharply marked lignocellulose reaction can be produced by the use of para-nitrophenyl sodium nitrosamine.[1] The 2 percent solution of the reagent is left in contact with the fibers for fifteen minutes, then removed by suction. The fibers are washed and saturated with 1 percent caustic soda solution. The reaction gives bright to dark lilac shades according to the degree of lignification; the weaker the lilac color the purer the cellulose. The colorations are still more distinct when, instead

[1] Schwalbe, *Zeit. f. ang. chim.*, 1902.

of the nitrosamine, a diazo solution is used, which is prepared from the nitrosamine solution by the action of hydrochloric acid and para-nitrodiazobenzene chloride. The fibers are soaked for fifteen minutes with the reagent as a 2 percent solution; remove by suction and wash with cold water. According to the degree of lignification the color will be more or less brown, pure cellulose being left white.

The degree of lignification may also be estimated by a solution of primuline; 0.25 gram of the fibers are dyed for one hour with 15 cc. of primuline solution (12 grams per liter) to which is added 5 cc. of $\frac{1}{2}$ percent salt solution. Wash and place in an acid solution of sodium nitrite (0.04 percent sodium nitrite solution and 5 cc. of $\frac{1}{2}$ percent sulfuric acid solution). Treat cold for fifteen minutes, then wash with cold water and stain with 10 cc. of a dilute beta-naphthol solution (0.014 percent). With cotton a red color is developed, but with lignified fibers the red color diminishes in proportion to their impurity.

Klason's reaction for lignin is carried out as follows: 22 mgms. of fiber are dissolved in 5 cc. of concentrated sulfuric acid in a glass-stoppered cylinder. The intensity of the brown color will indicate the degree of lignification.

The Maule reaction for lignin is also a very good one; the fibers are soaked in a 0.1 percent solution of potassium permanganate for fifteen minutes, thoroughly washed and placed in hydrochloric acid (specific gravity 1.06) until the brown deposit of manganese oxide is completely dissolved. After washing, ammonia gas is passed over the fibers. Lignified tissue acquires a red color by this treatment.

11. Detection of Cotton in Kapok.—The practice of some manufacturers of mixing comber waste with kapok in order to reduce the cost of the material has made it desirable that some simple test should be available for determining whether such mixture has taken place. As kapok is a partly lignified fiber it gives a yellow to yellowish brown coloration when treated with iodine and sulfuric acid, whereas cotton gives a blue coloration with this reagent. This same test also serves to distinguish the general class of Bombax cottons from ordinary cotton.

The only direct test to distinguish cotton and kapok is by means of the microscope. The cotton fiber is seen as a somewhat twisted, rather flat ribbon. The kapok fiber, on the other hand, appears as a round, smooth fiber, having in a marked degree a very distinct luster. Upon close observation this fiber is seen to have a very thin cell-wall, and to be almost entirely free from twists. There appear, however, at times, what seem to be joints or nodules. As a rule the contents of the cells are very indistinct, differing greatly from cotton in this respect.

Chemically, there is no test that will serve to distinguish these two fibers that can be applied and concluded rapidly, for the reason that both

are nearly pure cellulose, and respond in a very similar manner to the same reagents. It is quite possible to distinguish between cotton and kapok by the use of a 1 percent solution of aniline sulfate (about 4.5 grains of aniline sulfate in 1 oz. of water). If a small quantity of kapok is moistened with a few drops of this solution it will in a short time assume a distinct yellow color, which will not appear when cotton is subjected to the same reagent. This is due to the fact that the kapok fiber contains a trace of lignified tissue, which reacts yellow with aniline sulfate. This test can be conveniently made in a white china dish.

Kapok gives a reddish violet coloration with phloroglucinol and hydrochloric acid, whereas cotton furnishes only a faint violet coloration with this reagent.

Greshoff,[1] gives the following tests to distinguish between cotton and kapok: (*a*) zinc chloride and iodine solution gives a violet-blue coloration with cotton, but a yellow color with kapok; (*b*) by immersing the fibers for one hour in an alcoholic solution of Magenta (0.01 gram of Magenta in 30 cc. of alcohol and 30 cc. of water) cotton remains practically colorless, whereas kapok is dyed a bright red. A further test is with Schweitzer's reagent; this causes cotton to swell up and dissolve, while kapok is not affected. Greshoff claims that a quantitative estimation of cotton in kapok may be made by distillation of the material with hydrochloric acid and precipitation of the liberated furfural by phloroglucinol. Kapok contains 23 to 25 percent of pentosans (furfural yielding bodies) while cotton only has about 3 percent.

Another simple test is to immerse the samples for a few minutes in a chlorine solution and then squeeze out the surplus liquor. Place the sample in a saucer and pour on it a small quantity of ammonia. The cotton remains white and the kapok will become a reddish shade. In place of the chlorine solution, hypochlorite or chloride of lime can be used. The reddish shade of the kapok is characteristic, but does not remain on the fiber.

Still another method is to immerse the fiber in nitric acid for one minute, then rinse in water and immerse in ammonia. The cotton remains white and the kapok becomes yellow. Like the reddish shade with the last-mentioned test, the yellow color does not remain on the kapok.

12. Identification of Artificial Silks.—In Table IX are given Hassac's tests to identify the different varieties of artificial silks or forms of lustra-cellulose, and also the distinction between these latter and true silk. The reagents given in this table are prepared as follows:

(*a*) Glycerol-sulfuric acid: 10 cc. glycerol, 5 cc. water, 15 cc. conc. sulfuric acid.

(*b*) Potassium-iodo-iodide, 0.3 gram potassium iodide, 30 cc. water, and iodine in excess.

[1] *Chem. Central*, 1908, p. 647.

TABLE IX

REACTIONS OF NATURAL AND ARTIFICIAL SILKS

Reagent.	Natural Silk.	Collodion Silk.	Cuprate Silk.	Viscose Silk.	Acetate Silk.	Gelatine Silk.
Water	No change	Swells up			Slight swelling	Strong swelling
Ignition	Odor of burnt feathers, black residue	No odor, burns quickly, ash very small	No odor, burns quickly, leaves very slight ash	No odor, burns less quickly	Disagreeable odor, black residue	Odor of burnt feathers
Reaction of ignition gases with litmus	Alkaline	Acid	Acid	Acid	Acid	Alkaline
Iodine and sulfuric acid	Yellow	Violet blue, strong swelling	Pure blue, strong swelling	Pure blue, strong swelling	Yellow	Yellowish brown
Iodine in zinc chloride	Pale yellow	Reddish violet	Reddish violet	Reddish violet	Yellow	Yellowish brown
Cold concentrated sulfuric acid	Quickly dissolves	Quickly dissolves	Slowly dissolves	Quickly dissolves	Slowly dissolves	Strong swelling without solution
Acetic acid	No action	No action	No action	No action	Quickly dissolves	Cold, strong cleavage lines; boiling, rapidly dissolves

TABLE IX—*Continued*

REACTIONS OF NATURAL AND ARTIFICAL SILKS

Reagent.	Natural Silk.	Collodion Silk.	Cuprate Silk.	Viscose Silk.	Acetate Silk.	Gelatine Silk.
Semi-saturated solution of chromic acid	Dissolves slowly	Dissolves cold	Dissolves cold	Dissolves cold	Swells but does not dissolve	Dissolves rapidly when warmed
Diphenylamine and sulfuric acid	No action	Blue color in five minutes, slowly disappearing	No action	No action	No action	No action
Caustic potash (40%)	Dissolves without color	Swells without dissolving, liquid yellow			Swells greatly, but does not dissolve	Dissolves rapidly
Ammoniacal copper solution	Fibroin dissolves, sericin insoluble, much wrinkled up	Swells quicklyand dissolves slowly	Swells slowly and dissolves slowly	Swells and slowly dissolves	Slight swelling, but does not dissolve	Insoluble; liquid becomes violet
Alkaline copper glycerol solution	Dissolves quickly	No change	No change	No change	No change	Dissolves on boiling

(*c*) Zinc-chloro-iodide: 1.75 grams; zinc chloride, 30 cc. water; and iodine to saturation.

(*d*) Concentrated sulfuric acid.

(*e*) Chromic acid in half-saturated solution.

(*f*) Caustic potash in 45 percent solution.

(*g*) Ammoniacal solution of copper oxide prepared by dissolving oxide of copper in ammonia water to the point of saturation, and there passing through it a current of air freed from carbonic acid by a preliminary passage through a solution of caustic potash.

(*h*) Ammoniacal solution of nickel oxide prepared by dissolving 2 grams crystallised nickel sulfate in 30 cc. water, precipitating the nickel with caustic soda, filtering and redissolving the precipitate in ammonia water.

(*i*) Alkaline-glycerol solution of copper prepared by dissolving 3 grams copper sulfate in 30 cc. water and 1.75 grams glycerol, then adding sufficient caustic potash solution to just redissolve the copper hydrate at first precipitated.

(*j*) Acid solution of diphenylamine containing 1.57 grams diphenylamine and 25 cc. concentrated sulfuric acid.

The determinations should be checked by comparative tests on known types. If samples are dyed, the color should first be stripped by treatment with hydrosulfite, but care must be had in such cases as this treatment is likely to vitiate the reliability of certain of the reactions.

Collodion silk may be distinguished from viscose and cuprammonium silks by the fact that it will always contain at least a trace of nitrogen compound capable of giving the blue diphenylamine test and the red brucine test. According to Schwalbe collodion silk always contains a small amount of oxycellulose produced during the nitration process, and hence may be distinguished from other cellulose silks by the fact that this oxycellulose will cause a reduction of Fehling's solution. The test is made by heating 0.2 gm. of the artificial silk with 2 cc. of Fehling's solution, when a green color is obtained with collodion silk, while with viscose or cuprammonium silk the liquid remains blue. Schwalbe also recommends the use of a solution of 20 grams of zinc chloride, 2 grams of potassium iodide, and 0.1 gram iodine in 15 cc. of water as a reagent to distinguish viscose silk from cuprammonium silk. When equal quantities of the two silks are treated with this reagent and then washed with water, the viscose silk remains bluish green for some time, whereas the cuprammonium silk soon loses its brown color. This test, however, is not satisfactory, as it is difficult to obtain the proper color reactions.

Maschner [1] finds that even after considerable practice a microscopical examination is not a reliable means of distinguishing between different kinds of artificial silks. The most important chemical tests are the diphenylamine reaction recommended by Süvern for the detection of collodion silks, Schwalbe's reduction test with Fehling solution, for the same purpose, and the latter's test with a solution of zinc chlor-iodine to distinguish between cuprate and viscose silks. Maschner concluded that of

[1] *Färber. Zeit.*, 1910, p. 352.

these three reactions only the first is at all reliable as the other two give different results with even artificial silks of the same class. For the same reason the behavior of artificial silks toward dyestuff solutions is not a satisfactory method of distinction. A means to distinguish between the silks, however, is afforded by the action of concentrated sulfuric acid. The test is as follows: 0.2 gram of the silk to be examined together with an equal quantity of a standard artificial silk of known make are put in small dry Erlenmeyer flasks which stand on white paper and about 10 cc. of pure sulfuric acid are poured over them. The flasks are shaken to moisten thoroughly the fibers and the immediate effect of the acid is observed. The flasks are then kept under observation for about $1\frac{1}{2}$ hours. Collodion silk remains at first quite colorless and only after 40–60 minutes does the liquor assume a weak yellowish tone. Cuprate silk at once takes on a yellow or yellowish brown tone and the liquor becomes yellowish brown after 40–60 minutes. Viscose silk is at once turned reddish brown by the acid and the liquor after 40–60 minutes becomes a rusty brown color.

Collodion silk may be distinguished (though not in a very satisfactory manner) from viscose and cuprammonium silks by the microscopic appearance in polarised light.

Herzog, in Table X, gives the microscopical characteristics of artificial silks.

According to Beltzer a solution of Ruthenium Red (0.01 gram in 10 cc. of water) is a useful microchemical stain for the identification of artificial silks. Collodion silk is stained a deep red with this reagent, cuprate silk is scarcely tinted, while viscose silk is colored a deep pink. Artificial silks, however, which have been treated with formaldehyde (for increasing their resistance to water) are not stained by Ruthenium Red solution.

13. Distinction between True Silk and Different Varieties of Wild Silk.—True silk (from *Bombyx mori*) rapidly dissolves (one-half minute) in boiling concentrated hydrochloric acid; Senegal silk (from *Faidherbia*) dissolves in a somewhat longer time, while yama-mai, tussah, and cynthia silks require a much longer time for complete solution. True silk is also rather easily soluble in strong caustic potash solution, whereas the other varieties of silk are not. Silbermann [1] states that true silk may be distinguished from tussah silk by treatment with a semi-saturated solution of chromic acid, prepared by dissolving chromic acid in cold water to the point of saturation and then adding an equal volume of water. True silk is said to be completely dissolved on boiling in this solution for one minute, whereas wild silk remains insoluble. Chittick, however, on testing this method out has found that tussah silk will also dissolve under these conditions, and that the method cannot be employed to distinguish between the two varieties of silk. This chromic acid method

[1] *Die Seide*, vol. 2, p. 206.

TABLE X

MICROSCOPICAL COMPARISON OF ARTIFICIAL SILKS

Variety.	General Character of the Fiber in		Surface Markings.	Broken Ends.	Regularity in Breadth of Fiber.	Imperfections.
	Length.	Cross-section.				
Collodion silk	Broad and ribbon-like	Very irregular, trough-shaped, folded	Deep lines or folds	Always jagged	Rather irregular (25 percent)	Air bubbles and small granules
Cuprate silk	Cylindrical, often showing very fine internal lines	Oval to circular, somewhat squared	Finely grooved in places	Sharp edges	Less than 10 percent of irregularities	Air bubbles and small granules
Viscose silk	Cylindrical and more or less squared	Oval to circular, rather squared, like paving blocks	Sharp striations	Jagged	Less than 15 percent of irregularities	Air bubbles and small granules
Acetate silk	Cylindrical	Oval to circular, seldom squared	No striations	Sharp to jagged	Less than 5 percent of irregularities	Seldom any bubbles or granules
Gelatine silk	Cylindrical	Circular	No striations	Smooth	Less than 5 percent of irregularities	Large air bubbles and dark brown flecks

of separation is to be found generally quoted in the literature of silk technology and has evidently crept into the authorities without being properly tested out.

Süvern gives the following table showing the principal points of difference between ordinary silk, tussah silk, and artificial silk:

Reagent.	Chinese Raw Silk.	Tussah Silk.	Artificial (Chardonnet) Silk.
Potassium hydroxide solution, concentrated	Dissolves on gently warming	Dissolves on boiling	Unaltered
Potassium hydroxide, 40 percent solution	Acted on at 65° C. Dissolved at 85° C.	Swells up at 75°. Dissolves at 120° C.	Insoluble
Zinc chloride, 60 percent solution	Completely dissolved at 120° C.	Completely dissolved at 135° C.	Dissolves at 140° to 145° C.
Copper sulfate ammonia solution ($CuSO_4$, 10 grms.; glycerol, 10 cc.; 40 percent NH_3, 10 cc.)	Dissolves in 30 minutes at ordinary temperature	Scarcely attacked	Not attacked even on boiling
Cuprammonium solution	Dissolves with exception of slimy residue	Unattacked	Unattacked even on boiling
Fehling's solution	Dissolves readily on boiling	Dissolves on boiling	Not attacked
Millon's reagent	Violet coloration on boiling	Violet coloration on boiling	No change
Iodine solution	Deep brown coloration	Faint brown coloration	Brown coloration changing to blue
Ash, percent	0.95	1.15	1.60
Behavior at 200° C., and loss in weight	Becomes brown and friable; 11.15 percent	Scarcely altered; 11.21 percent	Blue-black coloration then carbonization. Friable with difficulty; 43 to 65 percent
Percentage of nitrogen	16.60	16.79	0.15
Percentage of water	7.99	8.26	10.37
Water absorbed in 48 hours, percent	2.24	5.00	5.24

Under the microscope true silk can readily be told from wild silks, as the latter fibers are broad and flat, and show very distinct longitudinal striations, which are absent in true silk. Exception must perhaps be made with the wild silk from *Saturnia spini*, which can scarcely be told from true silk by a microscopical examination. With regard to distinguishing between the different varieties of wild silks themselves, some valuable information may be gained by a determination of their relative

diameters. Höhnel gives the following values for the greatest thickness of the different silks:

		Microns.
True silk	(*Bombyx mori*)	20 to 25
Senegal silk	(*Faidherbia bauhini*)	30 to 35
Ailanthus silk	(*Attacus cynthia*)	40 to 50
Yama-mai silk	(*Antheræa yama-mai*)	40 to 50
Tussah silk	(*Bombyx selene*)	50 to 55
Tussah silk	(*Bombyx mylitta*)	60 to 65

According to Wiesner and Prasch, the breadths of the single fibers of different silks are as follows:

	Microns.
Ailanthus silk	7 to 27, mostly 14
Yama-mai silk	10 to 45, mostly 23
Bombyx mylitta	14 to 75, mostly 42
Bombyx selene	27 to 41, mostly 34
Senegal silk	12 to 34, mostly 22
True silk	9 to 21, mostly 13

True silk, ailanthus silk, and Senegal silk do not show any cross-marks, or only very faint indications of such; whereas with tussah silk and yama-mai silk the cross-marks are very distinct and characteristic.

The microscopical appearance of the end of the fiber on being torn apart also serves at times as a useful means of distinguishing the variety of silk; true silk, tussah silk, and yama-mai silk show scarcely any fraying at the ends; in Senegal silk the fraying is very noticeable in almost every fiber; while in ailanthus silk about one-half of the number of fibers show a frayed end.

14. Wild Silks of Minor Importance.—Besides the wild silks here mentioned, there are a few others of lesser importance, which for the sake of completeness are herewith described.

1. *Saturnia polyphemus*, a North American variety, consists of very flat fibers, with large air-canals and numerous structural filaments separating at the edge of the fiber; coarse lumps of adhering sericine are frequent; well-defined cross-marks are also frequent. The single fiber is about 33 microns in width; in its polariscopic appearance these fibers very much resemble ailanthus silk.

2. *Arryndia ricini*, the fibers are even more flattened than the preceding and resemble a thin band or ribbon; large air-canals are of frequent occurrence; striations very apparent; the sericine layer is in places very thin, and sometimes apparently lacking altogether. The double fiber is about 45 to 55 microns in width, and 4 to 6 microns thick. At the edge of the fiber frayed ends of structural filaments are often apparent. Cross-marks are rather ill-defined, but of frequent occurrence. The sericin layer, though thin, is quite uniformly developed.

3. *Antheræa pernyi* has a very flat fiber, resembling a ribbon; it does not fray out at the ends, and shows scarcely any single filaments. The double fiber measures 60 to 80 microns in width and 8 to 10 microns in thickness. Cross-marks are rather few and indistinct. The sericine layer is very thin, and in general hardly noticeable. Moderately sized air-canals are present.

4. *Saturnia cecropia* is to be found in Texas. The fiber is also flat and ribbon-like in form; the double fiber measures 60 to 90 microns in width and 10 to 15 microns

in thickness; air-canals are frequent and large, hence the fiber usually appears rather dark under the microscope. The cross-marks are very distinct, and at such points the fiber is much broader. The fiber is usually much frayed out and individual filaments are easily distinguished. The sericine layer is quite thin, but very uniform.

5. *Attacus lanula* has fibers which are not so flat as the preceding. The double fiber is 25 to 35 microns in width and 12 to 18 microns in thickness. The air-canals are fine and delicate; and the fiber shows but a slight degree of fraying. The sericine layer is very thin and finely granulated on the surface; in places it has the form of irregular shreds. The fiber as a whole has a brownish yellow appearance, due to the ochre-yellow color of the sericine layer.

15. Appearance of Silks under Polariscope.—By the use of the polariscopic attachment to the microscope, considerable differences can be observed in the interference colors displayed by the different varieties of silks. It is best to conduct these observations under a magnification of 30 to 50 diameters; and as the silk fibers are more or less ovoid in section, it must be borne in mind that the same fiber will give a different color phenomenon, depending on whether it is viewed from the narrow side or from the broad side. Hence, to obtain trustworthy results, the appearance of the same side only of the fibers should be compared. Also, the appearance of single fibers only, and not of crossed fibers, should be taken. Höhnel gives the following description of the appearance of the different silk fibers viewed in polarised light, the observations being made with a dark field, and under a magnification of 30 to 50 diameters:

1. *True silk:* (*a*) *broad side*, very lustrous, of a bluish or yellowish opalescent white; the same color is nearly always to be found over the entire breadth; (*b*) *narrow side*, exactly similar to the preceding.

2. *Yama-mai silk:* (*a*) *broad side*, generally of a pure bluish opalescent white; also darker bluish to almost black tones; nearly all of the colors are brilliant; (*b*) *narrow side*, shows all colors, very brilliant and contrasted; darker and blackish tones also occur.

3. *Tussah silk* (from *Bombyx selene*): (*a*) *broad side*, shows all colors, very brilliant; thickness of the fiber very uneven, hence the colors change through the length; the thick parts are dark blue and reddish violet, while the thinner parts are yellow or orange; (*b*) *narrow side*, shows bright red and bright green colors, though often but slightly visible; the colors form long flecks; often only dark gray to black.

4. *Tussah silk* (from *Bombyx mylitta*): (*a*) *broad side*, a bluish opalescent white prevailing; also brown, gray, and black tones; the colors occur in flecks like preceding, though scarcely even darker blue, but mostly bright orange to red or brown; (*b*) *narrow side*, color a dull gray with bright red or green flecks; the general appearance is very similar to the preceding silk.

5. *Ailanthus silk:* (*a*) *broad side*, bright yellow or yellow-brown to gray-brown colors; (*b*) *narrow side*, nearly all colors, but rather soft, and not very contrasted, seldom very bright, but rather dull; short flecks of green, yellow, violet, red, or blue.

6. *Senegal silk:* (*a*) *broad side*, bright yellowish white, gray to brown, seldom bluish white in color; (*b*) *narrow side*, faint and dull gray, brown to blackish colors, seldom bright colors.

Table XI presents the microscopical characteristics of the most important varieties of natural silk.[1]

[1] Herzog, *Die Unterscheidung der natürlichen und künstlichen Seiden*, p. 14.

TABLE XI

MICROSCOPICAL CHARACTERISTICS OF SILKS

Variety of Silk (Single Fiber).			General Character of Fiber.		Maximum Breadth of Single Fiber, Microns.	Fibrillæ Striation.	Cross-marks on Fiber.	Appearance of Fiber Ends after Rupture of Fiber.
			Length.	Cross-section.				
True Silk, (*Bombyx mori*)			Cylindrical, transparent	Circular very slightly flattened	20–25	None, or only very feebly developed	Very seldom	Little or no fraying at end of fiber
Wild Silks	Tussah Silk	*Bombyx mylitta*	Ribbon-form, flat, broad; only slightly transparent	Flat, pressed together, very often narrow and triangular	60–100	Very apparent	Very often easily observed between crossed Nicol's prisms	
		Bombyx selene			50–55			
	Yama-mai Silk *Antheræa yamamaya*				40–50	As with Tussah, but weaker		
	Ailanthus Silk, Fagara Silk, Attacus Cynthia				40–50	Especially distinct	Seldom	Great many fibers divided into shreds
	Senegal Silk, *Faidherbia bauhini*				30–35			Almost all fibers shredded
Muscle Silk (*Lana penna*) *Penna nobilis*			Flattened cylindrical seldom twisted olive brown in color	Elliptical	80–100	Slightly striated	Not present	No fraying

CHAPTER XXVII

TESTING OF TEXTILE FABRICS

1. Conditioning of Textiles.—In speaking of the hygroscopic quality of wool and silk, it was mentioned that these fibers were capable of absorbing a considerable amount of moisture, and that this amount varied within rather large limits, depending upon the conditions of temperature and humidity of the air to which it may be exposed. It may be readily understood from these facts that in the buying and selling of wool and silk goods upon a basis of weight, the question as to how much moisture is present becomes of great practical importance in determining the money value of the operation. In England and on the continent of Europe, this fact has been recognised for some time, and there have been established at the various European textile centers official laboratories where the percentage of moisture in textile materials is carefully ascertained, and the sales are based on the actual amount of normal fiber contained in the lot examined. These official laboratories are called "conditioning houses," and the process of determining the amount of moisture is termed "conditioning." The first official conditioning house was established at Lyons in 1805 for the conditioning of silk. There are now conditioning houses in several European cities, as also in New York and Philadelphia, and lately there has been one established in Shanghai.

In the conditioning of wool the operation is carried out as follows: Representative samples are taken from the lot under examination; these are mixed together, and three test samples of $\frac{1}{2}$ to 1 lb. each are taken. The test sample, after being carefully weighed, is placed in the conditioning apparatus and dried to constant weight at a temperature of 105° to 110° C. (220° F.). This weight represents the amount of dry wool fiber present in the sample, the loss in weight represents the amount of moisture the wool contained.

The amount of normal wool is obtained by adding to the dry weight of the wool the amount of moisture supposed to be present in the air-dried material under normal conditions of humidity and temperature. The added amount is termed *regain*, and is officially fixed by the conditioning house. This permissible percentage of regain varies with the form of the manufactured wool; the conditioning house at Bradford, England, for instance, has established the following figures:

	Regain, Percent.	Direct Loss, Percent.
Wools	16	13.79
Tops combed with oil	19	15.97
Tops combed without oil	18¼	15.43
Noils	14	12.28
Worsted yarns	18¼	15.43

In the instructions issued by the Manchester Testing House the removal of moisture from wool is considered complete when the material has been heated for forty minutes at 100° C. with proper ventilation. Woodmansey [1] studied the relative amounts of moisture removed from wool in different times, as follows:

	Percent.
Loss on heating 1 hour	13.84
After a further 3 hours	0.21
" " 3 hours	0.12
" " 5 hours	0.11
" " 10 hours	0.08

In these tests, however, the temperature was 150° C. and it is therefore probable that more than mere hygroscopic moisture was driven off.

The system of conditioning adopted at Bradford is as follows: The weights of the packages and conditions are taken by three persons independently on sensitive scales which are adjusted weekly. These scales have a weighing capacity from one-half pound to ten tons. In making the tests for moisture, the samples are carefully selected from various parts of the packages. The amount of the material taken for this purpose is for wools, noils, and wastes, about 2 lbs. from each package; for tops, three balls; for yarns in hank, about 4 lbs. in 1200 lbs; for yarns on bobbins or tubes, twenty to forty bobbins or tubes, and for yarns on cones, cheeses, etc., 5 to 15 lbs.

The standard regains and allowances are as follows:

Wools and waste, for moisture, a regain of 16 percent, equal to 2 ozs. 3¼ drs. per pound.

Tops combed with oil, for moisture, a regain of 19 percent, equal to 2 ozs. 9 drs. per pound.

Tops combed without oil, for moisture, a regain of 18¼ percent, equal to 2 ozs. 7½ drs. per pound.

Ordinary noils, for moisture, a regain of 14 percent, equal to 1 oz. 15½ drs. per pound. Clean noils, a regain of 16 percent, equal to 2 ozs. 3¼ drs. per pound.

Yarns, worsted, for moisture, a regain of 18¼ percent, equal to 2 ozs. 7½ drs. per pound.

Yarns, cotton, for moisture, a regain of 8¼ percent, equal to 1 oz. 4 drs. per pound.

[1] *Jour. Soc. Dyers & Col.*, 1918, p. 227.

Yarns, silk, for moisture, a regain of 11 percent, equal to 1 oz. 9¼ drs. per pound.
Cloths, worsted and woolen, a regain of 16 percent, equal to 2 ozs. 3¼ drs. per pound.

The conditioning house at Roubaix, on the Continent, allows the following percentages for regain on woolen materials:

	Percent.
Wools	14¼
Tops	18¼
Woolen yarns	17

The percentage of regain allowed at Bradford is considerably higher than that which would be allowed at most American textile centers.

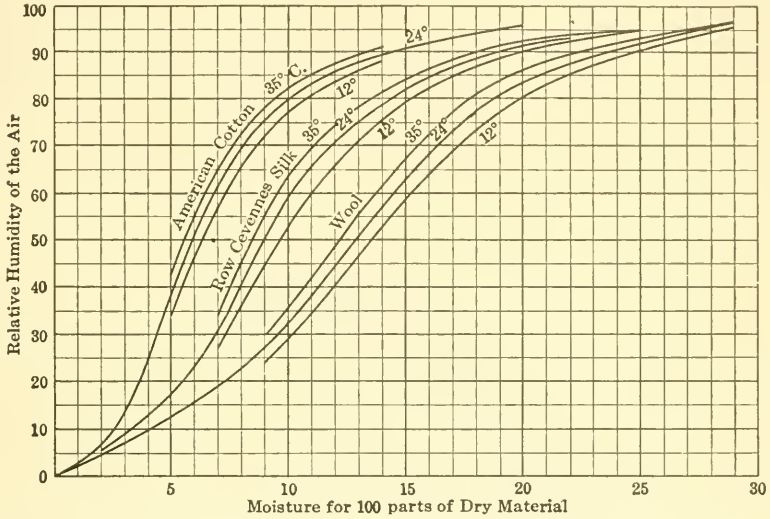


FIG. 403.—Effect of Humidity on Hygroscopic Quality of Fibers. (Schloesing.)

The author has found from many conditioning tests at Philadelphia that woolen yarns will average about 10 percent of moisture, worsted tops (in the oil) and loose wool about 12 percent, and woven fabrics of wool about 8 to 9 percent. This would correspond to a regain on the dry weight as follows:

	Percent.
Woolen yarns	11.1
Worsted tops and loose wool	13.6
Woolen cloth	9.9

In order to give fair regains for commercial purposes, the author would recommend for woolen yarns a regain of 12 percent; for tops and roving and loose wool, 15 percent; and for wool cloth, 11 percent. For silk the regain allowed should be 11 percent, and for cotton and vegetable fibers in general the regain should be 8 percent.

In the United States Government specifications for army blankets, etc., of wool, a regain of 11 percent is allowed.

Hartshorne gives the following table showing the regains of worsted yarns for various temperatures and percentages of humidity:

TABLE OF WORSTED REGAIN FOR VARIOUS TEMPERATURES AND PERCENTAGES OF HUMIDITY

Percentage Humidity.	Degrees Fahrenheit.					
	50.	60.	70.	80.	90.	100.
40	12.8	12.4	12.0	11.5	10.9	10.4
50	14.7	14.3	13.8	13.2	12.6	12.1
60	16.7	16.1	15.6	14.9	14.4	13.8
70	18.7	18.0	17.4	16.8	16.2	15.6
80	20.9	20.2	19.4	18.7	18.2	17.7
90	23.5	22.7	21.8	21.1	20.9	20.8
100	27.1	26.2	25.4	24.8	24.7	24.6

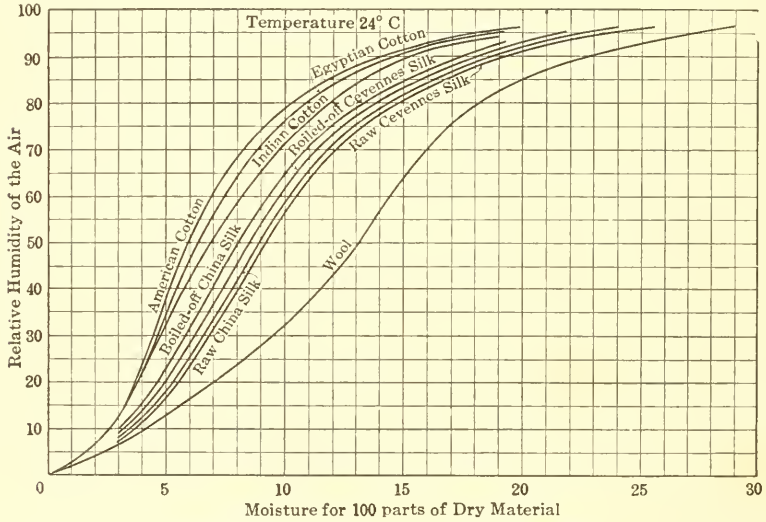


FIG. 404.—Effect of Humidity on Hygroscopic Quality of Different Varieties of Cotton and Silk. (Schloesing.)

Schloesing has plotted curves (Figs. 403 and 404) showing the relation between the humidity of the air and the moisture contained in air-dry textile materials.

Scheurer[1] conducted experiments to ascertain the amount of water fixed by various fibers at 100° C. in an atmosphere saturated with steam; his results were as follows:

[1] *Bull. Soc. Ind. Mulh.*, 1900, February.

Fiber, Previously Dried at 100° C.	Water Fixed, Percent.
Bleached white cotton	23.0
Unbleached linen	27.7
Unbleached jute	28.4
Bleached silk	36.5
Bleached and mordanted wool	50.0

According to Scheurer, these figures show that for the textile fibers there exists a fixed capacity of saturation which remains perfectly constant in the same atmosphere of steam, as soon as the equilibrium is once established.

The International Congress at Turin (1875) fixed the amount of "regain" for different textile fibers as follows:

	Percent.
Silk	11
Wool (tops)	18¼
Wool (yarn)	17
Cotton	8½
Linen	12
Hemp	12
Jute	13¾
New Zealand hemp	13¾

The adoption of 18.25 percent regain as the legal standard in France, according to Persoz [1] has led to the practice of worsted tops being excessively moistened before sale to the spinner. He recommends a reversion to the old standard, as he considers that 13 percent is the average amount of moisture in wool, and hence the weight for normal moisture should be found by adding 15 percent to the dry weight.

The following table shows the amount of moisture taken up by various fibers under different conditions of humidity and at a temperature of 75° F.

Percent, Relative Humidity.	Percent Moisture.			Percent, Relative Humidity.	Percent Moisture.		
	Cotton.	Silk.	Wool.		Cotton.	Silk.	Wool.
5	1.4	1.8	2.2	55	6.3	9.4	13.4
10	2.4	3.2	4.0	60	6.7	9.9	14.2
15	3.0	4.4	5.7	65	7.3	10.5	15.0
20	3.6	5.4	7.1	70	7.9	11.4	16.0
25	3.9	6.1	8.3	75	8.8	12.5	17.1
30	4.3	6.7	9.4	80	9.9	14.0	18.6
35	4.6	7.3	10.4	85	11.4	15.9	20.5
40	5.0	7.8	11.0	90	13.6	18.4	23.2
45	5.3	8.4	11.8	95	17.5	22.7	27.0
50	5.7	8.8	12.6				

[1] *Rev. Gen. Mat. Col.*, 1900, p. 81.

Lewis, of the National Bureau of Standards, has shown that the thtual regain in worsted tops varies with different relative humidities of ace air, the average for different grades of wool being as follows (at 70° F.):

Relative Humidity, Percent.	Regain, Percent.
45	13.33
55	14.51
65	15.37
75	16.38
85	18.92

It will be noticed that above 75 percent relative humidity the increase in regain is very marked. This Bureau has also made tests on the influence of varying humidity on the strength and count of worsted yarns. The following table shows the results of a large number of tests on different yarns (single and two-ply):

Tensile Strength at Different Humidity

Relative Humidity at 70° F., Percent.	Tensile Strength, Grams.
45	234
55	231
65	220
75	216
85	191

It will be noted that as the relative humidity increases the tensile strength of the worsted yarn decreases.

The influence of variation in the relative humidity in the yarn count and yardage of worsted yarns is shown in the following tables (at 70° F.):

Yarn.	Yarn Counts at Relative Humidity of			Difference Between 95% and 65% Relative Humidity.		Difference Between 65% and 85% Relative Humidity.		Difference Between 45% and 85% Relative Humidity.	
	45%.	65%.	85%.	Count.	Yardage per Lb.	Count.	Yardage per Lb.	Count.	Yardage per Lb.
20/1	20.25	19.77	18.82	0.48	269	0.95	532	1.43	801
24/1	24.58	23.97	22.79	0.61	342	1.18	661	1.79	1002
24/1	25.51	24.94	23.80	0.57	319	1.14	638	1.71	958
36/1	34.49	33.68	81.77	0.81	454	1.91	1070	2.72	1523
36/1	35.47	34.71	32.85	0.76	426	1.86	1042	2.62	1467
40/1	39.09	38.08	36.03	1.01	566	2.05	1148	3.06	1714
28/2	27.74/2	27.18/2	25.68/2	0.56	314	1.50	840	2.06	1154
36/2	34.28/2	33.66/2	31.80/2	0.62	347	1.86	1042	2.48	1389

The method of calculating the amount of normal wool may be illustrated by the following example: A lot of 1000 lbs. of loose wool was submitted for conditioning; ten samples of 1 lb. each were taken from different parts of the lot; these were mixed together and three samples of 250 grams each were taken for testing. On drying to constant weight the three samples lost, respectively, (1) 12.25 percent, (2) 12.30 percent, (3) 12.22 percent, making the loss 12.26 percent. Hence in the entire lot of 1000 lbs. of wool there were 122.6 lbs. of moisture or $1000-122.6=877.4$ lbs. of dry wool. The permissible amount of regain in this case was 15 percent; hence the amount of normal wool would be $\left(877.4\times\right)\frac{15}{100}+877.4=1009$ lbs. instead of 1000 lbs.

2. Apparatus for Conditioning.—The apparatus employed for the conditioning test is usually one of such a construction as to be especially adapted for the purpose. The form may differ somewhat in details with different makers, but a typical conditioning oven may be described as follows:

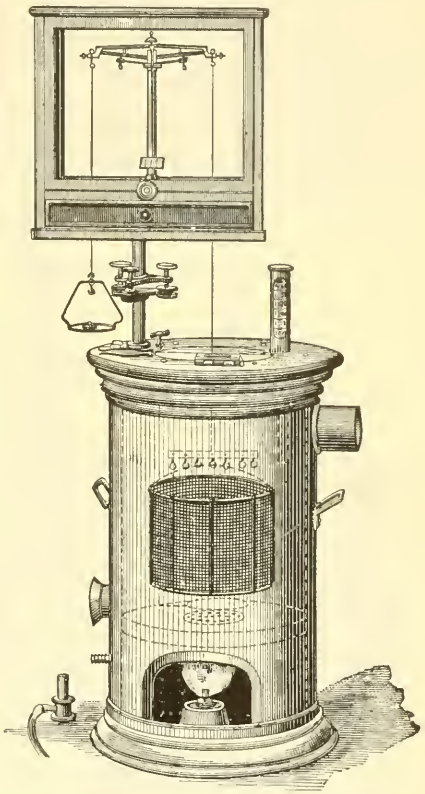


Fig. 405.—Conditioning Apparatus.

The apparatus consists of an upright oven heated by a flame placed in the lower chamber. An even temperature is maintained by so conducting the currents of heated air that they pass completely around the inner chamber or oven containing the sample to be tested (see Fig. 405). A thermometer projecting into the oven from above is employed for indicating the temperature, and this may be maintained at the desired point by a proper regulation of the supply of heat. The material to be conditioned, in whatever form (as loose wool, yarn, etc.) is placed in a wire basket suspended from one arm of a balance fixed outside and above the oven; the weight of the basket and its contents is counterpoised by placing definite weights on a scale-pan suspended from the other arm of the balance. As the material diminishes in weight through the volatilisation of its moisture, the loss is noticed from time to time by removing the necessary weights from the scale-pan in order to restore the equilibrium of the balance. When the weight becomes constant after heating at 110° C., the total loss is recorded, and this figure repre-

sents the amount of moisture which was originally present in the material tested. The balance is usually enclosed in a suitable case in order to protect it from draughts of air whereby its sensibility would be impaired. Better control in conditioning may be obtained by using electrically heated apparatus (Fig. 406) and most modern conditioning laboratories at the present time are equipped with this form of oven.

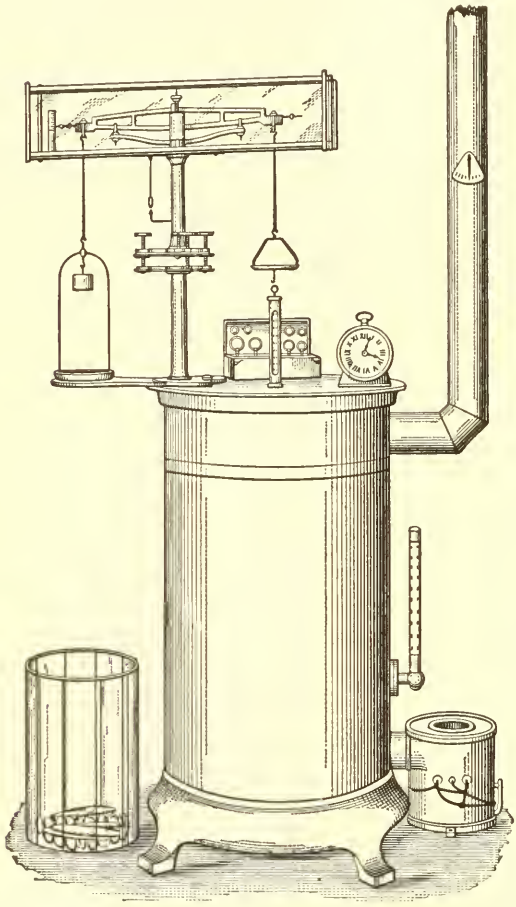


Fig. 406.—Electrically Heated Conditioning Apparatus.

The Wilson conditioning apparatus (shown in Fig. 407) is a form used in England. It is a gas-heated oven and is provided with accessory apparatus consisting of two fans, one for blowing fresh air in, and the other for removing the moist air. A reheater is also provided for using up the waste heat from the oven.

Another modern American type is the Freas conditioning oven (Fig. 408). This oven is electrically heated and is provided with a special type of thermostatic control so that the temperature may be accurately maintained at any desired degree. The oven itself is also provided with ten baskets suspended from a movable frame which may be rotated as desired so that any of the baskets may be brought on to the weighing rod without being removed from the oven. This arrangement permits of making accurate tests at constant temperatures without exposure of the samples to the outside air, and thereby eliminates very materially the chances of error due to the sample taking up moisture during the weighing. The oven is also provided with convenient observation windows and a low-speed motor providing a

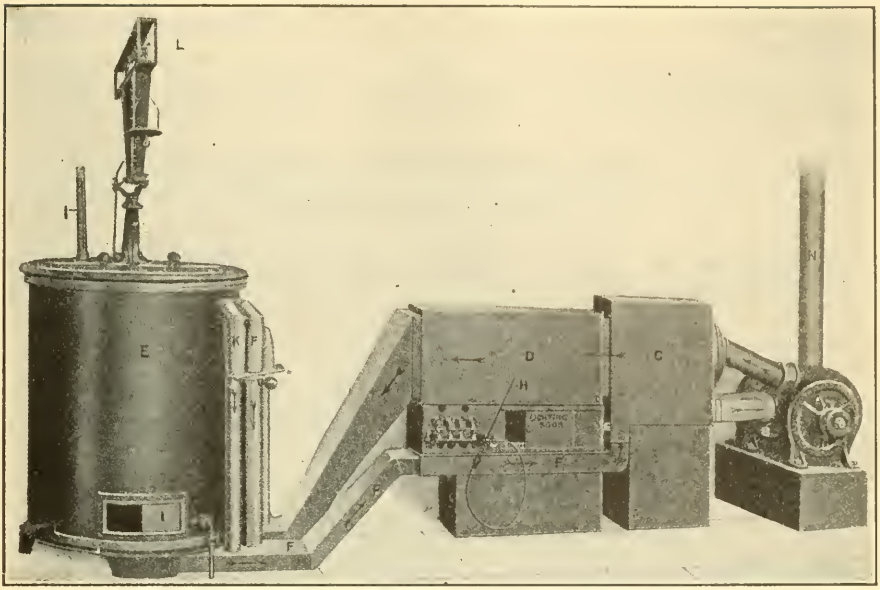


FIG. 407.—Wilson Conditioning Apparatus.

forced circulation of the heated air which rapidly removes the moisture and prevents the material from being "stewed" in its own moisture. The chain movement permitting the baskets being moved, changed and weighed is also controlled from the outside.

3. Calculations Involved in Conditioning.—In the conditioning of wool (or of any other textile material), there are certain calculations necessary which it may be advisable at this point to explain. The two principal calculations to be made involve the determination of the percentage of moisture based on the weight of the material as taken for the test (that is, on its moist weight), and then the determination of the conditioned weight of the material based on a definite percentage allowance of "regain," this percentage being calculated on the dry weight

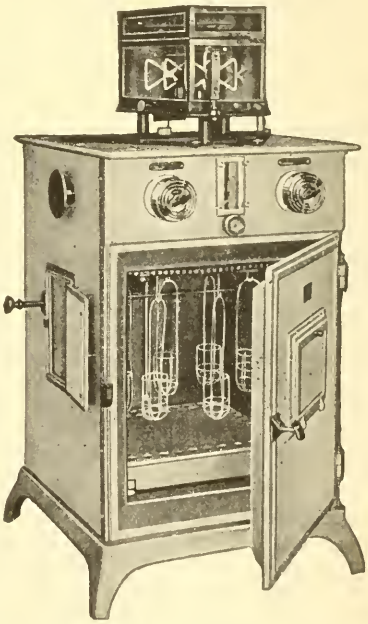


FIG. 408.—Freas Conditioning Oven with Special Thermostatic Regulation of Temperature.

of the material. The different problems in conditioning will now be considered.[1]

(1) If a weight (w) of material after drying shows a weight (a), what percentage (x) of moisture does it contain?

$$w-a = \text{loss in weight on drying} = \text{moisture}.$$

$$\frac{w-a}{w} \times 100 = x, \text{ percent of moisture}.$$

(2) If a quantity of material of weight (w) contains x percent of moisture, what is its dry weight (a)?

$$a = w\left(1 - \frac{x}{100}\right).$$

(3) If from a weight (W) of material there is taken a sample of weight (w) and the dried weight of this is found to be (a), what will be the conditioned weight (C) of the material, allowing a regain of (R) per cent?

The dry weight (A) of the entire material will be

$$A = W \times \frac{a}{w},$$

and the conditioned weight will be

$$C = W \times \frac{a}{w}\left(1 + \frac{R}{100}\right).$$

(4) A substance is conditioned with a regain of (R) percent, what percentage of moisture (x) does it contain?

We have the proportion

$$\frac{100+R}{R} = \frac{100}{x};$$

therefore

$$x = \frac{100R}{100+R}.$$

The following table shows the percentage of moisture in any material corresponding to a definite percentage of regain:

Percent Regain.	Percent of Moisture.	Percent Regain.	Percent of Moisture.
5	4.76	12	10.71
6	5.66	12.5	11.11
7	6.54	13	11.50
7.5	6.98	14	12.28
8	7.41	15	13.04
8.5	7.83	16	13.79
9	8.26	17	14.53
10	9.09	18	15.25
11	9.91	19	15.97
		20	16.67

[1] See Persoz, *Essai des Matières Textiles.*

(5) If the material contains (x) percent of moisture, what will be the corresponding percentage of regain (R)?

This is the reverse of the previous problem. We have

$$R = \frac{100x}{100 - x}.$$

The following table shows the percentage of regain of any material corresponding to a definite percentage of moisture:

Percent of Moisture.	Percent Regain.	Percent of Moisture.	Percent Regain.
5	5.26	13	14.94
6	6.38	14	16.28
7	7.53	15	17.65
8	8.70	16	19.05
9	9.89	17	20.48
10	11.11	18	21.95
11	12.36	19	23.46
12	13.64	20	25.00

Hartshorne has worked out some mathematical relations concerning the laws of regain of moisture in cotton and worsted. His general conclusions are as follows: (1) The general law for cotton and worsted (and probably for any other textile fiber) may be expressed by the formula,

$$HKRT^3 = H(5771.44 \times 10^8),$$

in which H represents any given percent of relative humidity, R the regain at any absolute temperature T, K a variable coefficient depending upon both H, R, and T in such a way that for $H = 1$, the product KRT^3 is a constant quantity represented by the number 5771.44×10^8. This constant number, 5771.44, is the weight in grains of a cubic foot of water vapor at any temperature multiplied by the corresponding absolute temperature, expressed in degrees Fahrenheit, divided by the maximum elastic force of water vapor at that temperature, expressed in inches of mercury. (2) For any given temperature the relations of values of R to the variable K, for both worsted and cotton, is expressed by a hyperbolic equation differing for each substance. (3) For any other temperature the law for worsted is: For the same humidity the squares for the regains at different temperatures are to each other inversely as the cubes of the corresponding absolute temperatures. (4) The law for cotton is: For the same humidity the first powers of the regains at different temperatures are to each other inversely as the first powers of the corresponding absolute temperatures.

(6) If a material is required to possess a definite conditioned weight (C), what percentage of regain (R) must be applied to the dry weight (a)?

We have the proportion

$$\frac{a}{C-a}=\frac{100}{R},$$

therefore

$$R=100\,\frac{C-a}{a}.$$

(7) If the dry weight (a) of any material is given, what quantity of water (q) would it have to absorb in order to contain (x) percent?

We have the proportion

$$\frac{100-x}{x}=\frac{a}{q};$$

therefore

$$q=\frac{ax}{100-x}.$$

The weight (W) of the material after absorbing the moisture would be

$$a+q,$$

or

$$W=\frac{100a}{100-x}$$

(8) If the dry weight (a) of a material is given, what would be its conditioned weight (C), allowing (R) percentage of regain?

We have in this case

$$C=a\left(1+\frac{R}{100}\right).$$

(9) If the conditioned weight (C) of a material is given with a percentage of regain (R), what is its dry weight (a)?

From the previous formula we have

$$a=\frac{100C}{100+R}.$$

(10) If the percentage of moisture (x) is known in a material, what will be the conditioned weight (C), allowing a regain of (R) percent?

The dry weight (a) will be

$$a\left(1-\frac{x}{100}\right).$$

Therefore the conditioned weight with (R) percent regain will be

$$C=a\left(1-\frac{x}{100}\right)\left(1+\frac{R}{100}\right).$$

(11) If the original weight (W) of a material is known and also its conditioned weight (C), what percentage difference in weight (D) would there be between the original weight and the conditioned weight?

We have the proportion

$$\frac{W}{W-C}=\frac{100}{D};$$

therefore

$$D=\frac{100(W-C)}{W}.$$

There would be a gain or loss by conditioning according to whether (W) is greater or less than (C).

(12) If the conditioned weight (C) of a material is given and also its percentage difference (D) on conditioning, find the original weight (W) of the substance.

From the previous formula we have

$$W=\frac{100C}{100-D}.$$

(13) If the original weight (W) of a material is known and also the percentage difference (D) on conditioning, find the conditioned weight (C).

From the previous formula we have

$$C=\frac{W(100-D)}{100}.$$

(14) If a material contains (x) percent of moisture, calculate the difference (d) between its original weight (W) and its conditioned weight (C) with a regain of (R) percent.

This difference is

$$d=W-C,$$

and from the formula under (10) we have

$$d=W-W\left(1-\frac{x}{100}\right)\left(1+\frac{R}{100}\right);$$

hence

$$d=\frac{W[(100+R)x-100R]}{10{,}000}.$$

If (W) in this formula is taken as equal to 100, the expression becomes simplified to

$$d=D=\left(1+\frac{R}{100}\right)x-R.$$

According to the value of (x) this difference will be positive or negative; that is to say, the material will lose or gain by conditioning.

If

$$x \text{ is greater than } \frac{100R}{100+R}$$

there will be a loss.

If

$$x=\frac{100R}{100+R}$$

the fiber will be in its conditioned state.

Finally, if

$$x \text{ is less than } \frac{100R}{100+R}$$

the material will gain in weight by conditioning.

(15) If the difference (d) between the original weight (W) of a material and its conditioned weight (C) at a regain of (R) percent is known, find the percentage of moisture (x) in the material.

This is the reverse of the preceding problem and may be solved by taking the reciprocal of the formula for (d), as follows:

$$x=\frac{100(WR+100d)}{W(100+R)}.$$

If we take the original weight as equal to 100 and call (D) the corresponding difference, the expression becomes

$$x=\frac{100(R+D)}{100+R}.$$

It is necessary to remember in these formulas that the value of (d) or (D) is positive only if the original weight is greater than the conditioned weight; if the contrary is the case, the difference will be of a negative value. For example, a sample of wool *loses* 2 percent on conditioning at 15 percent regain; hence it contains

$$\frac{100(15+2)}{100+15}=14.7 \text{ percent moisture,}$$

whereas if it *gains* 2 percent in weight by conditioning, we have

$$\frac{100(15-2)}{100+15}=11.3 \text{ percent moisture.}$$

(16) A sample of material shows a difference in weight of (D) percent on conditioning at (R) percent regain, what difference (D') would there be if conditioned at a regain of (R') percent?

If we call the dry weight (a), then

$$D=100-a\left(1+\frac{R}{100}\right),$$

$$D'=100-a\left(1+\frac{R'}{100}\right).$$

Hence, by eliminating (a), we have

$$D'=\frac{(100+R')D-100(R'-R)}{100+R}.$$

This problem will often arise in practice where two different sets of regains are to be allowed. For example, a sample of wool conditioned at a regain of 15 percent loses 0.4 percent in weight, how much would it lose if the regain allowed was 17 percent?

$$D'=\frac{(117\times 0.4)-(100\times 2)}{115}=-1.3 \text{ percent;}$$

that is to say, the fiber would *gain* 1.3 percent in weight.

(17) A sample of material on conditioning at a regain of (R) percent shows a loss of (D) percent, what regain would have to be adopted in order that the loss may be (D') percent?

From the previous formula we have

$$R'=\frac{100(D+R)-D'(100+R)}{100-D}.$$

(18) If the conditioned weight (C) at a regain of (R) percent is known, calculate the conditioned weight (C') at a regain of (R') percent.

From the formula under (8) we have

$$\frac{C}{C'}=\frac{100+R}{100+R'};$$

hence

$$C' = C\,\frac{100+R'}{100+R}.$$

(19) In a textile material consisting of two kinds of fibers, if the percentage conditioned amounts of the two fibers are known, (C) and (C'), and their respective regains are (R) and (R'), what will be the average regain (r) and the average amount of moisture (x) in the mixture?

If (C) and (C') are the conditioned weights of the two fibers, their dry weights (A) and (A') would be

$$A = \frac{100C}{100+R}, \quad \text{and} \quad A' = \frac{100C'}{100+R'};$$

the average moisture would be

$$x = 100 - \left(\frac{100C}{100+R} + \frac{100C'}{100+R'}\right);$$

hence

$$x = 100\left[1 - \left(\frac{C}{100+R} + \frac{C'}{100+R'}\right)\right].$$

The average regain would be

$$r = \frac{100x}{100-x}.$$

For example, suppose we have conditioned a yarn composed of 65 percent of wool and 35 percent of cotton, with respective regains of 15 and 7 percent. Then

$$x = 100\left[1 - \left(\frac{65}{115} + \frac{35}{107}\right)\right],$$

$x = 9.6$ percent moisture,

$r = 10.6$ percent average regain.

(20) In a textile of mixed fibers if the proportion (P) and (P') of the two fibers is known on the dry weight (A), together with the moisture (x) lost on drying, what would be the conditioned weight (C) of the material, allowing (R) and (R') respectively as the regains for the two fibers?

We have

$$\frac{P}{100}A = \text{amount of first fiber},$$

$$\frac{P'}{100}A = \text{amount of second fiber},$$

and

$$\left(\frac{PA}{100}\times\frac{R}{100}\right) + \frac{PA}{100} = \text{conditioned weight of first fiber}.$$

$$\left(\frac{P'A}{100}\times\frac{R'}{100}\right) + \frac{P'A}{100} = \text{conditioned weight of second fiber}.$$

Adding these two terms gives us

$$A\left(1 + \frac{PR+P'R}{10{,}000}\right) = \text{conditioned weight of entire material}.$$

For example, suppose a yarn contains 60 percent of wool and 40 percent of cotton on a dry weight of 85 lbs., allowing respective regains of 15 and 7 percent, what would be the conditioned weight of the yarn?

$$85\left(1 + \frac{60\times15+40\times7}{10{,}000}\right) = 85\times1.118 = 94.83 \text{ lbs.}$$

TABLE SHOWING THE CONDITIONED WEIGHT OF 100 POUNDS OF ANY MATERIAL WITH REGAINS OF 7, 11 AND 15 PERCENT, CONTAINING DIFFERENT AMOUNTS OF MOISTURE

Percent, Moisture.	Conditioned Weight, Regains.			Percent, Moisture.	Conditioned Weight, Regains.		
	7 Percent.	11 Percent.	15 Percent.		7 Percent.	11 Percent.	15 Percent.
5.0	101.65	105.45	109.25	9.0	97.37	101.01	104.65
.1	101.54	105.34	109.14	.1	97.26	100.90	104.53
.2	101.44	105.23	109.02	.2	97.16	100.79	104.42
.3	101.33	105.12	108.91	.3	97.05	100.68	104.30
.4	101.22	105.01	108.79	.4	96.94	100.57	104.19
.5	101.12	104.90	108.68	.5	96.84	100.46	104.07
.6	101.01	104.78	108.56	.6	96.73	100.34	103.96
.7	100.90	104.67	108.45	.7	96.62	100.23	103.84
.8	100.80	104.56	108.33	.8	96.51	100.12	103.73
.9	100.69	104.45	108.22	.9	96.41	100.01	103.61
6.0	100.58	104.34	108.10	10.0	96.30	99.90	103.50
.1	100.48	104.23	107.99	.1	96.19	99.79	103.38
.2	100.37	104.12	107.87	.2	96.09	99.68	103.27
.3	100.26	104.01	107.76	.3	95.98	99.57	103.16
.4	100.15	103.90	107.64	.4	95.87	99.46	103.04
.5	100.05	103.79	107.53	.5	95.77	99.34	102.93
.6	99.94	103.67	107.41	.6	95.66	99.23	102.81
.7	99.83	103.56	107.30	.7	95.55	99.12	102.70
.8	99.72	103.45	107.18	.8	95.45	99.01	102.58
.9	99.62	103.34	107.07	.9	95.34	98.90	102.47
7.0	99.51	103.23	106.95	11.0	95.23	98.79	102.35
.1	99.40	103.12	106.84	.1	95.12	98.68	102.24
.2	99.30	103.01	106.72	.2	95.02	98.57	102.12
.3	99.19	102.90	106.61	.3	94.91	98.46	102.01
.4	99.08	102.79	106.49	.4	94.81	98.35	101.89
.5	98.98	102.68	106.38	.5	94.70	98.23	101.78
.6	98.87	102.56	106.26	.6	94.59	98.12	101.66
.7	98.76	102.45	106.15	.7	94.48	98.01	101.55
.8	98.66	102.34	106.03	.8	94.37	97.90	101.43
.9	98.55	102.23	105.92	.9	94.27	97.79	101.32
8.0	98.44	102.12	105.80	12.0	94.16	97.68	101.20
.1	98.34	102.01	105.69	.1	94.05	97.57	101.08
.2	98.23	101.90	105.57	.2	93.95	97.46	100.97
.3	98.12	101.79	105.46	.3	93.84	97.35	100.85
.4	98.01	101.68	105.34	.4	93.73	97.24	100.74
.5	97.90	101.57	105.23	.5	93.62	97.12	100.62
.6	97.80	101.45	105.11	.6	93.52	97.01	100.51
.7	97.69	101.34	105.00	.7	93.41	96.90	100.39
.8	97.58	101.23	104.88	.8	93.30	96.79	100.28
.9	97.48	101.12	104.77	.9	93.19	96.68	100.16

TABLE SHOWING THE CONDITIONED WEIGHT—*Continued*

Percent, Moisture.	Conditioned Weight, Regains.			Percent, Moisture.	Conditioned Weight, Regains.		
	7 Percent.	11 Percent.	15 Percent.		7 Percent.	11 Percent.	15 Percent.
13.0	93.09	96.57	100.05	17.0	88.81	92.13	95.45
.1	92.98	96.46	99.94	.1	88.71	92.02	95.34
.2	92.88	96.35	99.82	.2	88.60	91.91	95.22
.3	92.77	96.24	99.71	.3	88.49	91.80	95.11
.4	92.66	96.13	99.59	.4	88.38	91.69	94.99
.5	92.55	96.01	99.48	.5	88.28	91.57	94.88
.6	92.45	95.90	99.36	.6	88.17	91.46	94.76
.7	92.34	95.79	99.25	.7	88.06	91.35	94.65
.8	92.23	95.68	99.13	.8	87.95	91.24	94.53
.9	92.12	95.57	99.02	.9	87.85	91.13	94.42
14.0	92.02	95.46	98.90	18.0	87.74	91.02	94.30
.1	91.91	95.35	98.78	.1	87.63	90.91	94.18
.2	91.81	95.24	98.67	.2	87.52	90.80	94.07
.3	91.70	95.13	98.56	.3	87.42	90.69	93.96
.4	91.59	95.02	98.44	.4	87.31	90.58	93.84
.5	91.49	94.90	98.33	.5	87.21	90.46	93.73
.6	91.38	94.79	98.21	.6	87.10	90.35	93.61
.7	91.27	94.68	98.10	.7	86.99	90.24	93.50
.8	91.16	94.57	97.98	.8	86.88	90.13	93.38
.9	91.05	94.46	97.87	.9	86.78	90.02	93.27
15.0	90.95	94.35	97.75	19.0	86.67	89.91	93.15
.1	90.84	94.24	97.64	.1	86.56	89.80	93.04
.2	90.74	94.13	97.52	.2	86.45	86.69	92.92
.3	90.63	94.02	97.41	.3	86.35	89.58	92.81
.4	90.52	93.91	97.29	.4	86.24	89.47	92.69
.5	90.42	93.79	97.18	.5	86.13	89.36	92.58
.6	90.31	93.68	97.06	.6	86.02	89.24	92.46
.7	90.20	93.57	96.95	.7	85.92	89.13	92.35
.8	90.09	93.46	96.83	.8	85.81	89.02	92.23
.9	89.98	93.35	96.72	.9	85.71	88.91	92.12
16.0	89.88	93.24	96.60	20.0	85.60	88.80	92.00
.1	89.77	93.13	96.48	.1	85.49	88.69	91.88
.2	89.67	93.02	96.37	.2	85.38	88.58	91.77
.3	89.56	92.91	96.26	.3	85.28	88.47	91.66
.4	89.45	92.80	96.14	.4	85.17	88.36	91.54
.5	89.34	92.68	96.03	.5	85.06	88.25	91.43
.6	89.24	92.57	95.91	.6	84.95	88.13	91.31
.7	89.13	92.46	95.80	.7	84.85	88.02	91.20
.8	89.02	92.35	95.68	.8	84.74	87.91	91.08
.9	88.92	92.24	95.57	.9	84.63	87.80	90.97
				21.0	84.53	87.69	90.85

4. Analysis of Weighting in Silk Fabrics.—The practice of adding to the weight of silk in the dyeing and finishing operations has become so common that it is frequently desirable to ascertain in a sample of silk goods the amount of true fiber present and the amount and character of weighting. Lewitzki [1] calls attention to the fact that raw silk is sometimes found to be adulterated with weighting materials. These consist chiefly of soap, fat, and glycerol and some silk is also colored with Methyl Orange. Such silk had obviously been reeled from all sorts of old cocoons and then tinted with Methyl Orange to give it the appearance of a uniform product.

Black-dyed silk is especially liable to contain a very large amount of weighting materials; sometimes the degree of weighting may reach as high as 400 percent or even more. Colored silks are usually not weighted to such a great extent, but they will frequently be found also to contain considerable adulteration. Black-dyed silks are mostly loaded with Prussian blue and iron tannate, the latter being obtained by immersing the silk in a solution of pyrolignite or nitrate of iron, and subsequently in a solution of cutch or other tannin. Colored silks are principally weighted with tin phosphate obtained by treating the material with solutions of tin perchloride and sodium phosphate. Sometimes light-colored silks are also weighted with sugar, magnesium chloride, etc. Such materials are soluble in warm water, and hence their use is easily detected.

A convenient test which is frequently applicable to detect weighting is to ignite the silk fiber; if it is heavily weighted it will not inflame, but gradually smolder away and leave a coherent ash retaining the original form of the fiber.

In general the substances which may be present as weighting materials are iron, as ferrocyanide or tannate; tin, as tannate, tungstate, phosphate, silicate, or hydroxide; chromium compounds; the sulfates or chlorides of sodium, magnesium, and barium; organic matters, such as sugar, glucose, gelatine, tannins, etc.

The following method is one which has been recommended for the qualitative analysis of weighting materials on silk:[2] Substances that are easily soluble, such as sugar, glucose, glycerol, magnesium salts, etc., are estimated directly by boiling the silk with water and testing the extract with Fehling's solution, etc.[3] From 2 to 3 grams of the silk are ignited

[1] *Färber.-Zeit.*, 1911, p. 42.

[2] Silbermann, *Chem. Zeit.*, vol 18, p. 744.

[3] Fehling's reagent is an alkaline solution of copper sulfate containing potassium tartrate. It is prepared in the following manner: 34.639 grams of pure crystallised copper sulfate are dissolved in about 250 cc. of water; 173 grams of Rochelle salt (sodium potassium tartrate) are dissolved in the same quantity of water; 60 grams of caustic soda are similarly dissolved. The three solutions are then mixed, and the mixture diluted to 1000 cc. with water. The reagent is employed as follows: 10 cc. of the solution are diluted with 40 cc. of water and brought to a boil; there is then

and the ash is tested for tin (which may be present in the fiber as basic chloride and stannic acid), chromium, iron, etc.

These metals may be tested for in the ash in the following manner: Moisten with a few drops of nitric acid and re-ignite in order to be certain that all carbon is removed. Treat the residue with eight to ten drops of strong sulfuric acid; and gently heat until fumes are evolved; allow to cool and boil with water, dilute to about 100 cc. with water, and then pass hydrogen sulfide gas through the liquid; filter, and examine the solution and precipitate as follows: The aqueous solution may contain zinc or iron; add a few drops of bromine water to remove excess of hydrogen sulfide and to oxidise any iron present to the ferric condition; boil, then add ammonia in slight excess; boil again, and filter; if there is a precipitate, it may contain iron; if so, it should be brown in color; dissolve in a little hydrochloric acid and add a few drops of a solution of potassium ferrocyanide; a blue color will confirm the presence of *iron*. The filtrate, which may contain zinc, should be heated to the boil, and a few drops of potassium ferrocyanide solution added; a white precipitate will indicate *zinc*. The original precipitate produced by the treatment with hydrogen sulfide is next examined. This may contain lead, tin, or copper; it is fused for ten minutes in a porcelain crucible with 2 grams of a mixture of potash and soda ash together with 1 gram of sulfur. On cooling, the mass is boiled with water and filtered. The residue may contain lead and copper; it is boiled with strong hydrochloric acid and a few drops of bromine water are added for the purpose of completely oxidising any copper sulfide present; filter if necessary, and add to the filtrate an excess of ammonia, when a blue color will indicate presence of *copper*. Acidulate the liquid with acetic acid and divide into two portions: to the first add a few drops of a solution of potassium bichromate; a yellow precipitate will confirm the presence of *lead;* to the other add a few drops of a solution of potassium ferrocyanide, when a brown precipitate or coloration will indicate presence of copper. The filtrate from the residue after the above fusion is acidulated with acetic acid, when a yellow precipitate of stannic sulfide will indicate the presence of *tin*. The latter test may be confirmed by dissolving the precipitate of stannic sulfide in hydrochloric acid and bromine water. The filtered solution is then boiled with small pieces of metallic iron to reduce the

added a portion of the solution to be tested for sugar (or glucose) which has previously been boiled with a small quantity of dilute hydrochloric acid. If sugar is present, the Fehling's solution will be decolorised and a bright red precipitate of cuprous oxide will be thrown down. This test may be made quantitative by using a known quantity of sugar solution, filtering off the cuprous oxide, igniting, and finally weighing as copper oxide (CuO). In order to determine the amount of sugar (or glucose) corresponding to this latter, reference should be made to tables constructed by Allihn showing the proper equivalents of sugar and glucose for the amounts of copper oxide determined.

tin; the liquid is diluted and filtered and a drop of mercuric chloride solution is added, when a white or gray turbidity will be produced if tin is present.

Fatty matters, wax, and paraffine are detected by extraction with ether or benzene.

Japan tram silk is sometimes weighted with fatty substances. The normal amount of fat in raw silk never exceeds 0.06 percent. A direct determination of the fatty matters may be made by treating 5 grams of the silk sample in a stoppered flask with pure benzene three or four times successively, using about 60 cc. of the solvent each time and allowing it to act from two to four hours with frequent shaking. The several portions of benzene are brought together and evaporated to dryness in a tared dish and the fatty residue is weighed. Another method is to extract with ether in a Soxhlet apparatus.

To detect mineral weighting the silk is soaked in warm dilute hydrochloric acid (1 : 2) after complete removal of fatty matters; if the fiber is almost decolorised by this treatment, only a slight yellow tint remaining, while the solution assumes a deep brownish color not changed to violet by addition of lime-water, it is safe to conclude that the silk has been weighted by alternate passages through baths of iron salts and tannin. The yellow color of the fiber is due to a residuum of tannin, and the precise shade (from greenish to brownish yellow) enables some idea to be formed as to the nature of the tanning material used (sumac, divi-divi, cutch, etc.). Decolorisation of the fiber, the acid extract being pink, and changing to violet by lime-water, indicates a logwood black. If the fiber retain a deep greenish tint and the solution be yellow and unaffected by lime-water, the black is dyed on a bottom of Prussian blue. If the latter has been produced during the final stage of dyeing, this will be shown by its solubility in the acid. A green fiber and pink solution, changing to violet on addition of lime-water, indicate a logwood black dyed on a bottom of Berlin blue. In the hydrochloric acid solution, such metals as lead, tin, iron, chromium, and aluminium may be determined. Blacks produced by artificial dyes on a bottom of iron-tannin or iron-blue-tannin may be recognised by the coloration imparted to acid and caustic soda solutions. With blacks produced solely with coal-tar dyes, treatment with a hydrochloric acid solution of stannous chloride does not affect aniline and alizarine blacks; naphthol black is changed to reddish brown, and wool black becomes yellowish brown. Tannin materials in general may be extracted by alkalies, and subsequently precipitated and distinguished by ferric acetate. To remove the whole of the weighting material and the dye, the silk should be boiled with acid potassium oxalate, washed with dilute hydrochloric acid, and finally treated with soda solution. When iron and tin are both present in the fiber, it is best to first extract the tin by treatment with a solution of sodium sulfide.

Persoz recommends in testing for tin weighting on dark-colored and black silks to boil the sample for a few minutes in concentrated hydrochloric acid. Then dilute and filter the acid, and pass hydrogen sulfide into it, when a yellow precipitate (SnS) would indicate the presence of tin.

Vignon has proposed using the specific gravity of the silk sample as a means of determining the proportion of weighting materials present; but this method cannot be recommended as being at all practical, as the specific gravity of the weighting materials themselves would have to be known. The specific gravity of the silk may readily be determined as follows: A small sample is weighed as usual in the air; it is then suspended in benzene and the weight again taken. The difference between the two weighings will give the loss of weight in benzene; this loss divided into the original weight in air and multiplied by the density of the benzene will give the specific gravity of the silk. The specific gravity of silk and of other fibers determined in this way is as follows:

Silk, raw	1.30 to 1.37
Silk, boiled-off	1.25
Wool	1.28 to 1.33
Cotton	1.50 to 1.55
Mohair	1.30
Hemp	1.48
Ramie	1.51 to 1.52
Linen	1.50
Jute	1.48

For the examination of white silk Allen recommends the following:[1] (1) The total *soluble weighting materials* are determined by treating a known weight of the sample four to five times with hot water, redrying, and weighing. The Milan Commission fixed a limit of 1.5 percent for the proportion of soluble materials, and gave the method for their determination as follows: The dried silk is heated for thirty minutes with ten times its weight of distilled water at 50° to 55° C. in a closed metal tube; the water being then changed and the heating continued for another thirty minutes, at the same temperature. As the hygroscopic character of silk is very variable, it is best to employ a blank sample of a standard silk, and after redrying until the blank sample has regained its normal weight the test sample is weighed, the loss representing the matters soluble in water. In the solution, after suitable evaporation, *glucose* may be determined directly by means of Fehling's solution, and *cane-sugar* after inversion by boiling with dilute hydrochloric acid. Sulfates and chlorides and magnesium may be detected and determined as usual. *Sulfates* are detected by a small portion of the solution in a test-tube, adding a few drops of dilute hydrochloric acid and then a few drops of a solution of

[1] *Commer. Org. Anal.*, vol. 4, p. 527.

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[1] *Commer. Org. Anal.*, vol. 4, p. 527.

between each bath. The silk must be carefully handled, as it becomes quite brittle; after drying at 110° C. it is weighed; the loss in weight represents the total weighting materials. As a certain loss of silk occurs in this treatment, the amount of weighting material found is generally somewhat in excess of the truth. The chief source of error, however, is in the uncertainty of the allowance to be made for loss in the weight of the silk by boiling off. For boiled-off silk this figure (d) is taken at 25 percent; for souple silk at 8 percent; for écru at 0 percent; and for fancy silks at 10 percent. Calling p the original weight of the sample, and D the weight after treatment, the percentage of weighting, W, may be calculated from the following formula:

$$W = \frac{(100-d)\times(p-D)}{D}.$$

In cases where the treated silk leaves a sensible amount (A) of ash on ignition, the following formula must be used:

$$W = \frac{(p-D+1.25A)\times(100-d)}{D-1.25A},$$

as the weight of the ash, if multiplied by the factor 1.25, will give approximately the amount of metallic hydroxides retained by the treated silk.

The foregoing method of Silbermann, however, is not sufficiently accurate for such a long and tedious process.

According to Ristenpart [1] the weighting on silk may be determined by extracting 1–3 grams of the sample with 25 cc. of a 4 percent solution of caustic soda. He considers this more expeditious than the nitrogen method, while it is sufficiently accurate for all practical purposes. It will not answer, however, for iron mordanted silk, in which case, it is recommended to extract the organic matter, and subsequently estimate the ash.

The method of analysing weighted silk, recommended by Königs of the silk-conditioning establishment at Crefeld, is as follows: (1) Determine *moisture* by drying at 110° C.; (2) *Fatty matters* by extraction with ether; (3) Boil out the *silk-glue* with water; (4) Dissolve out *Prussian blue* with dilute caustic soda; reprecipitate by acidifying and adding ferric chloride, ignite precipitate with nitric acid, and weigh as ferric oxide; 1 part of $Fe_2O_3 = 1.5$ parts of Prussian blue; (5) Estimate *stannic oxide* in ash of silk and calculate as catechu tannate of tin; 1 part of $SnO_2 = 3.33$ parts of catechu tannate; (6) Estimate total *ferric oxide* in ash, subtract that existing as Prussian blue, and the amount naturally present in dyed silk (0.4 to 0.7 percent), and calculate the remainder to tannate of iron; 1 part of $Fe_2O_3 = 7.2$ parts of ferric tannate.[2]

[1] *Färb. Zeit.*, 1909, p. 126.

[2] Persoz states that in many silk works in Lyons it is the custom to resort to the

For the extraction of weighting materials from black-dyed silk Heermann [1] recommends the use of a mixture of equal parts of glycerol and normal potassium hydroxide solution. The sample of silk is heated with this reagent to about 80° C. on the water-bath for ten minutes. Black dyes and Prussian blue are rapidly extracted by this reagent without injury to the silk fiber. In case the weighting materials contain tin compounds in addition to Prussian blue, successive extractions should be given with the glycerol-alkali solution, with cold 20 percent hydrochloric acid, and again with glycerol-alkali.

Perhaps the most accurate method of analysing silk for total amount of weighting is to determine the amount of nitrogen present as silk by Kjeldahl's process.[2] To do this it is first necessary to remove all gelatine, Prussian blue, or other nitrogenous matters.[3] This is effected by boiling a weighed quantity of the silk (about 2 grams) with a 2 percent solution of sodium carbonate for thirty minutes. The silk is then washed, and heated to 60° C. for thirty minutes in water containing 1 percent of hydrochloric acid, and afterward well washed in hot water. This treatment with alkali and acid should be repeated until the sample no longer has a blue color. With souple or écru silks, ammonia or ammonium carbonate should be used instead of sodium carbonate, and the silk should be finally boiled for an hour and a half in a solution containing 25 grams of soap per liter. After this preparation the nitrogen determination is conducted as follows: The sample is placed in a round-bottomed flask of hard glass, and treated with about 20 cc. of strong sulfuric acid, with the addition of a single drop of mercury. The flask is then heated, gently at first, and then to a vigorous boil; then 10 grams of potassium sulfate are added and the boiling continued until the contents of the flask are clear and colorless. The contents are then washed into a distilling-flask and connected with a suitable condenser. By means of a tap-funnel, an excess of caustic soda solution is gradually added, together with a little sodium sulfide to decompose any nitrogen compounds of

following method of calculation, which, however, he considers as too empirical: The proportion of ash of the silk sample having been obtained, the weight is (1) multiplied by 1.27 and (2) the product is subtracted from 100, and (3) the difference is multiplied by 4/3, and (4) the number so obtained is divided into 1000, and (5) from the quotient 100 is subtracted. The figure that is finally obtained represents the amount of weighting. This method, however, does not seem to work out sensibly from the percentage of ash, and Persoz must have incorrectly reported the mathematical operations involved.

[1] *Färber. Zeit.*, 1909, p. 75

[2] Gnehm and Blenner, *Rev. Gen. Mat. Col.*, April, 1898.

[3] According to Sisley (*Rev. Gen. Mat Col.*, 1907) the amount of nitrogen in dry fibroine, obtained as a mean of a number of analyses of various authorities, is 18.4 percent. This figured to air-dried silk with 11 percent of moisture would be 17.4 percent. The proper factor would then be 5.62 instead of 5.68.

mercury that may have been formed. Some granulated zinc is placed in the flask to prevent bumping, and the distillate is collected in a measured quantity of standard acid, which takes up the ammonia that distils over. Excess of acid is determined by titration with standard alkali, using Methyl Orange as an indicator of neutrality. The above method is based on the fact that when silk (in common with the great majority of other nitrogenous organic substances) is heated with concentrated sulfuric acid, the whole of the nitrogen present is eventually converted into ammonia. Air-dried silk with 11 percent of hygroscopic moisture contains 17.6 percent of nitrogen, consequently the amount of true silk in a sample may be obtained by multiplying the percentage of nitrogen found by the factor 5.68. This method yields very accurate results if the determination of the nitrogen is carefully conducted.

Sisley recommends that the Kjeldahl method be carried out as follows: About 2 grams of the silk are boiled for ten minutes with a 25 percent acetic acid solution, then rinsed in water, immersed for ten minutes in a 3 percent solution of trisodium phosphate at 50° C., rinsed again, and then boiled twice for twenty minutes in a solution containing 3 percent of soap and 0.2 percent of sodium carbonate. The silk thus purified is wrapped in a piece of cotton cloth and gently heated with 20 cc. of strong sulfuric acid, 10 grams of potassium sulfate, and 0.5 gram of copper sulfate until effervescence ceases, after which the liquid is boiled until colorless, and the ammonia distilled in the usual manner.

Persoz[1] recommends the following method for the examination of black silks: A sample is taken weighing from 4 to 5 grams, being allowed to first acquire its normal amount of moisture before weighing, as drying at high temperatures may remove moisture which should be regarded as weighting. The sample is then treated to the alternate action of cold acid and alkaline solutions, flasks of about 250 cc. capacity being particularly useful for this purpose as with them quite a number of samples may be treated simultaneously. The acid solution is prepared with 3 volumes of water and 1 volume of commercial hydrochloric acid, while the alkaline solution consists of caustic soda lye of 6° Tw. These reagents when employed in the cold do not attack the fibroine as would be the case if heat were employed. After the first acid bath the liquor becomes charged with logwood and iron salts and acquires a reddish appearance. At the end of about thirty minutes the sample is removed, rinsed, pressed and then placed in the alkaline liquor. In this bath the logwood, fustic, cutch and other astringents pass into solution; also Prussian blue which is largely employed as a base for logwood black, is destroyed by the caustic soda, leaving on the fiber oxide of iron, which is removed by the subsequent treatment with acid. Some advantage

[1] *Rev. Gen. Mat. Col.*, 1906, p. 322.

is gained by adding to the alkaline liquor a small quantity of sodium sulfide, as the sulfides formed on the fiber are more readily dissolved in the succeeding acid bath. After thirty minutes' treatment in the alkaline bath the sample is removed, washed, and submitted to the action of a fresh portion of the acid solution. This treatment is repeated alternately until the silk has lost the greater amount of its coloring matter. When the reagents are seen to remove no further matter from the silk the sample is then boiled for thirty minutes in a 2 percent soap bath, followed by a thorough rinsing with hot distilled water. The silk will now show the appearance of a light brown or maroon color, indicating that the fiber still retains a considerable part of the astringent matters. The sample is then steeped in a bath containing 1 volume of hydrogen peroxide and 3 volumes of water at 60° C. and a small quantity of magnesium hydrate. This treatment will remove most of the cutch, which otherwise is difficult to eliminate. The sample is then thoroughly rinsed in hot and cold water, dried and conditioned in the air, and weighed. The sample is then incinerated to a complete ash to obtain the mineral matter.

Moyret recommends the following method for the analysis of weighted silks:

(*a*) *Moisture.*—This is best determined in a proper conditioning oven, but if this is not available it is sufficient to dry 10 grams of the silk in an oven at 110° C. for one hour, or until constant weight is obtained. If the loss exceeds 15 percent it may be assumed that the silk has been weighted with hygroscopic substances.

(*b*) *Soluble Matters.*—The dried sample is boiled in distilled water, mixed, dried, and weighed. Such substances as glycerol, sugar, magnesium sulfate, potassium sulfate, etc., will pass into solution, and the loss in weight will represent soluble matters.

(*c*) *Extract with Petroleum Ether.*—The sample is extracted for twenty minutes with petroleum, dried, and weighed. Loss in weight represents extractive matters. The extract may be evaporated and examined.

(*d*) *Action of Hydrochloric Acid.*—The sample is treated for fifteen minutes at 100° F., with dilute (1 : 2) hydrochloric acid. If ferric tannate has been used for weighting, the silk will become decolorised and the acid liquid will have a dirty brown color which does not turn violet on the addition of lime-water. Should the reddish solution turn violet with this latter reagent, logwood is indicated; while if the fiber becomes dark green and the liquid yellow and unchanged by lime-water, Berlin blue is present. If the fiber is green and the liquid red, changing to violet with addition of lime-water, it indicates logwood black dyed on a ground of Berlin blue. Iron, chrome, and alumina mordants must be tested for in the solution.

(*e*) *Action of Alkalies.*—The silk is next boiled in a dilute solution of soda ash, which will dissolve the tannin from the fiber. The tannin may be detected by addition of iron salts to the alkaline solution.

(*f*) *Estimation of Ash.*—A weighed sample of the silk is ignited in a crucible (platinum preferred). If the weight is more than 1 percent it indicates that the silk has been weighted, and the ash should be further examined.

A method for the determination of the weighting on silk which appears to be capable of yielding very good results is that suggested by

Gnehm.[1] It depends on the fact that the silk fiber does not appear to be injured by treatment with either hydrofluosilicic acid or hydrofluoric acid. The method is carried out as follows: About 2 grams of the silk to be tested are immersed, with frequent stirring, for one hour at the ordinary temperature of 100 cc. of a 5 percent solution of hydrofluosilicic acid. The treatment is then repeated with 100 cc. of fresh acid of the same strength. The silk is then washed several times with distilled water and dried. The loss in weight corresponds to the amount of inorganic weighting materials present. This method serves very well with silk weighted with stannic phosphate and silicate, but does not appear to be suitable for the estimation of weighting on black-dyed silks containing iron salts. It is said that oxalic acid may also be used,[2] for the purpose of removing the inorganic weighting materials from silks, without injury to the silk fiber itself.

Zell describes a method as follows: A sample of 1 to 2 grams of the silk is immersed in water for five minutes at 80° to 100° C., then treated for fifteen to twenty minutes at 50° to 60° C. with a $1\frac{1}{2}$ percent solution of hydrofluoric acid contained in a copper vessel. The sample is then pressed between filter papers, treated for fifteen minutes at 50° to 60° C. with a 5 percent solution of hydrochloric acid, washed in warm water, boiled for fifteen minutes in a 3 percent soap bath, treated for fifteen minutes in a warm soda bath, and rinsed in boiling distilled water.

Gnehm and Dürsteler[3] give the following rapid extraction methods for the analysis of weighted silks:

(*a*) *For White or Colored Silks.*—The sample is twice extracted for fifteen minutes with hydrofluoric acid of 1 to 2 percent strength at 50°–60° C. In the case of silk weighted with tin silicate and phosphate the material may be treated with dilute hydrochloric acid and hydrogen sulfide at 70°–80° C. for thirty minutes, then for five minutes with a 4 percent solution of sodium sulfide at 40°–50° C., and lastly for fifteen minutes with a 2 percent solution of sodium carbonate at 60°–70° C. The residue after this treatment may be weighed as pure silk fibroine. If aluminium compounds are present in the weighting these extractions must be repeated.

(*b*) *For Black Silks.*—If the weighting material is tin phosphate alone, extract with hydrofluoric acid (1–2 percent solution), and follow by a treatment with a 2 percent solution of sodium carbonate. In the presence of iron compounds it is best to extract the silk with a 1 percent solution of hydrochloric acid, then with a 4 percent solution of sodium sulfide, and finally with a 2 percent solution of sodium carbonate.

Taking all things into consideration, the author considers the following method to be the one best adapted for the commercial analysis of tin-weighted silks: A portion (about 0.5 gram) of the sample is placed in a weighing-bottle and dried in an air-bath at 105° C. to constant weight. It is then boiled in a 2 percent solution of hydrofluoric acid for five minutes,

[1] *Zeits. Farben- u. Text. Chem.*, 1903, p. 209.
[2] Müller, *Zeits. Farben- u. Text. Chem.*, 1903, p. 160.
[3] *Färber. Zeit.*, 1906, p. 218.

rinsed with water, and boiled for five minutes in a 2 percent solution of soda ash and washed. This alternate treatment with the hydrofluoric acid and soda ash solutions is repeated three times, after which the sample is finally rinsed, dried at 105° C., and reweighed. The loss in weight will represent weighting materials. The hydrofluoric acid may be prepared by diluting 11 cc. of commercial hydrofluoric acid to 400 cc. with water, and the soda ash solution by dissolving 2 grams of sodium carbonate in 100 cc. of water. Three alternate treatments with these reagents will generally suffice to remove all weighting materials without appreciable injury to the silk fiber, though to be accurate the treatments should be repeated until no further loss in weight is observed. This method gives good results if the weighting consists of tin-phosphate-silicate. For black silks heavily weighted with iron salts, and especially if Prussian blue is present in any considerable amount, the results will be low, and it is recommended to employ the Kjeldahl nitrogen method as described in the foregoing pages.

After carefully testing out the hydrofluoric method under varying conditions, the U. S. Testing Co. adopted the following procedure for the determination of the weighting on tin weighted silk:

A. 1. Dry sample for two hours at 105° C. and weigh. (Bone-dry weight of sample should be between 1 and 2 grams.)
2. Boil sample in 250 cc. distilled water for at least thirty minutes. (This step removes water-soluble finishing materials.)
3. Dry sample at 105° C. to constant weight. The loss in weight represents the amount of water-soluble finishing materials. (The above preliminary process is essential for practically all commercial samples, which usually contain 2 percent to 10 percent of finishing materials.)

B. 1. Warm 100 cc. hydrofluoric acid solution (approximately 2 percent) to 60° C. Immerse sample and work it in the bath for twenty minutes, not allowing the temperature to exceed 75° C. at any time. (It is safer to keep the temperature between 60° and 70° C. for the entire time of stripping.)
2. After rinsing the acid-treated sample in water, immerse it in a bath of soda ash (approximately 2 percent) held at 60°–65° C. Work sample as before and remove at end of twenty minutes.
3. Sample is thoroughly rinsed and dried to constant weight at 105° C. The loss by this operation represents the amount of tin weighting in the sample.

C. 1. Determine the amount of residual mineral matter in the silk after the preceding treatment, by the usual ash method, i.e., burning off all organic matter. (This final step should be carried out in all cases to check up the completeness of the stripping operations.)

5. Calculations in Silk Weighting.—The amount of weighting on silk is usually calculated on a basis of ounces per pound of raw silk, and expressed between a limiting variation of 2 ozs.; and it is further reckoned that 1 lb. of raw silk is equivalent to 12.4 ozs. of pure silk fiber (boiled-off). A sample of silk described as 22/24, for example, would mean that 22 to 24 ozs. of such silk would be equivalent to 16 ozs. of raw silk. The amount

of weighting as determined by the chemist should be calculated to percentage on the actual silk present, and then by use of the following table the corresponding ounces may be found:

Percent Weighting.	Ounces.	Percent Weighting.	Ounces.
0– 13	12/14	142–158	30/32
13– 29	14/16	158–174	32/34
29– 45	16/18	174–190	34/36
45– 61	18/20	190–206	36/38
61– 77	20/22	206–222	38/40
77– 93	22/24	222–238	40/42
93–109	24/26	238–254	42/44
109–125	26/28	254–270	44/46
125–142	28/30	270	46/48

For example: A sample of silk dried at 105° C. to constant weight proved to be 0.45 gram. After treatments with hydrofluoric acid and soda ash solutions as above described, dried again at 105° C., and reweighed, gave 0.31 gram of silk as a residue. Hence,

0.45 gram = weighted silk;
0.31 " = pure silk;

0.14 " = weighting,

and

$$\frac{0.14 \times 100}{0.31} = 45 \text{ percent weighting,}$$

calculated from a basis of pure silk. By reference to the foregoing table, it is seen that 45 percent weighting corresponds to 18/20 ozs.

If the percentage calculation for the weighting is made on a basis of the weighted silk instead of the pure silk, the following table is to be used:

Percent Weighting.	Ounces.	Percent. Weighting.	Ounces.
0–11	12/14	59–61	30/32
11–22	14/16	61–64	32/34
22–31	16/18	64–66	34/36
31–38	18/20	66–67.5	36/38
38–44	20/22	67.5–69	38/40
44–48	22/24	69–70.5	40/42
48–52	24/26	70.5–72	42/44
52–56	26/28	72–73	44/46
56–59	28/30	73–74	46/48

In the example given above, the calculation would be

$$\frac{0.14\times100}{0.45}=31 \text{ percent weighting}$$

on the basis of the weighted silk. By reference to the table this is seen to correspond to 18/20 ozs.

As the silk fiber is very uniform in its structure and weight for any given length, an empirical method for determining the weighting on silk is as follows: The size of a cocoon-thread (boiled-off) averages $2\frac{1}{4}$ denier; that is to say, 500 meters of such a filament will average 0.125 gram in weight. Hence, if yarn is being tested, a sample is observed under the microscope and the number of individual filaments present is counted. A convenient length of the yarn is then taken and weighed, and from this the weight of 500 meters is calculated. As there are two single filaments to a cocoon thread, by multiplying the number of filaments observed by the factor 0.0625, we obtain the weight of 500 meters of the yarn as pure silk. The difference between this weight and the former represents weighting, from which the percentage and ounces of weighting may be calculated as given in the foregoing paragraphs.

For example: A portion of a single thread from a skein of silk yarn was carefully teased out so as to separate the individual filaments, and these were counted under a microscope. A series of three observations gave 19, 17 and 20 filaments, or a mean of 18.6. The weight of 50 meters of the silk was 0.1312 gram. Hence

$0.1312\times10 = 1.312$ grams = weight of 500 meters of weighted silk;

$0.0625\times18.6 = 1.162$ " = weight of 500 meters of pure silk;

0.150 " = weighting,

and

$$\frac{0.150\times100}{1.312}=12.2 \text{ percent weighting,}$$

and this is equivalent to 14/16 ozs.

In case the sample to be examined is a woven fabric, it will be necessary to pick apart the warp- and weft-threads, and make separate counts of the filaments in each; then definite lengths of these threads may be measured off and weighed, and the calculation conducted as before. In making the count of the filaments in each thread of silk, the latter should be teased out as carefully as possible, in order to separate the individual filaments. This may readily be done by laying the thread on a glass microscope slide slightly moistened with water and separating the filaments with a needle. The number of filaments may then be counted through the microscope, using a low magnification. The count may also be made with the aid of a good magnifying-glass, but with more difficulty

and less accuracy than when a microscope is employed. At least three separate counts of different threads should be made, and the average of these taken as the true number.

In case the length of the silk threads is measured in yards and not meters, a convenient amount to take for a test is 20 yds., then the following formula will hold:

Let

A = weight of 500 meters of the weighted silk = weight of 20 yds. $\times 27.3$;

B = weight of 500 meters of pure silk = number of filaments $\times 0.0625$,

and

$$\frac{A-B}{A} \times 100 = \text{percent of weighting.}$$

The above formula is for weights expressed in grams; in case the weights employed are grains, we have

A = weight of 20 yds. $\times 27.3$;

B = number of filaments $\times 0.956$,

and

$$\frac{A-B}{A} \times 100 = \text{percent of weighting.}$$

These formulas may be simplified as follows:

(*a*) In case gram weights are used

w = weight of 20 yds. of the silk;

n = number of filaments;

$$\frac{436w-n}{w} \times 100 = \text{percent of weighting.}$$

(*b*) In case grain weights are used

$$\frac{28.4w-n}{w} \times 100 = \text{percent of weighting.}$$

The accuracy of this method for determining the degree of weighting of silk is based on the theory that the fiber is very uniform in size, and hence the weight of a given length of fiber may be assumed as being constant. This, however, is only true within certain limits and with respect to certain grades of silk. By reference to the table in Chapter VI, it will be seen that the variation in size (or weight for a given length) of silks from different countries is quite considerable; hence, to apply the foregoing method properly, the origin of the silk should be known. In the case of tussah or other varieties of wild silk the variation in size is much more considerable; hence the limit of error in this method is much larger and the results are not sufficiently accurate to be at all reliable.

Interesting comment on the accuracy of analysis of weighted silk is to be found in a report by a committee of the Silk Association of America (1914). This committee had an exhaustive series of tests made by the U. S. Bureau of Standards, by a chemist of Yale University, the chemists of the two most prominent silk dyeing firms, by a German chemist, and by the chemist of a leading silk manufacturer, in order to determine with what degree of accuracy such tests could be made. Results showed that in the analyses of various samples of silk goods where the actual percentage of weighting was known, the amounts returned by the various chemists differed considerably, especially in the case of black silks. The analyses made on the tin-weighted silks agreed much more closely, but when the weighting used was other than metallic or was a mixture of metallic and vegetable materials, very inaccurate results were obtained. This was especially true of the class of fabrics commercially known as "tailoring dyes."

6. Oil and Grease in Yarns and Fabrics.—An estimination of the amount of oil and grease is frequently required for woolen or worsted cloth, yarn, tops, roving, etc. A method leading to approximate results, which are generally sufficiently accurate for commercial purposes, is to weigh off a sample of the material to be tested and scour it for thirty minutes in a solution containing 5 grams of good quality soap per liter at a temperature of 140° F. It is then rinsed well in warm water a couple of times to remove all of the soapy liquor, and then dried. Before reweighing it should be left in the air for about an hour, so as to come to the same hygroscopic condition as when first weighed. The loss in weight will represent the oil, grease, and any dirt in the fiber, and may be called the "scouring loss."

A more accurate method to determine the oil and grease is to weigh off about 5 grams of the material and agitate in a flask with about 100 cc. of petroleum ether for twenty minutes. This will dissolve all oily matters present, and the liquid may be poured into a weighed evaporating-dish. The residual fiber is washed with about 100 cc. more of petroleum ether; the latter is added to the first extraction and the whole evaporated to dryness on a water-bath, and the weight of the residue of oil in the evaporating-dish is determined, or the extracted fiber may be removed from the flask, dried, exposed to the air for an hour and reweighed, and the loss in weight will represent grease and oil.

In the two preceding methods where the air-dry weights are used, care should be especially taken to weigh the material before and after under the same hygroscopic conditions, otherwise considerable variations in results may be obtained by reason of the fiber absorbing a greater or less quantity of moisture; where accurate results are demanded, it will be necessary to make three weighings, as follows: (*a*) the weight of the

air-dry material, (*b*) the weight of the material after drying at 105° C. for one hour, (*c*) the weight of the extracted material after drying for one hour at 105° C. In this manner the somewhat uncertain factor of moisture is eliminated. The percentage of grease in the matrial, however, should be calculated on the weight of the air-dry fiber.

For example: A sample of woolen yarn weighing 5.026 grams was dried at 105° C. for one hour and when weighed again gave 4.516 grams; after extraction with petroleum ether and drying again as before, it weighed 4.271 grams. The amount of grease in this case was therefore $4.516 - 4.271 = 0.245$ gram or $(0.245 \times 100) \div 5.026 = 4.67$ percent.

A still better and more accurate method for the determination of grease is to treat a weighed sample of the material in a Soxhlet extraction apparatus with petroleum ether, evaporating off the solvent and weighing the residue of grease. The analysis is determined as follows: The small flask of the apparatus is weighed and then about half-filled with petroleum ether (about 50 to 75 cc.); about 2 grams of the material to be extracted is accurately weighed and placed in the extraction tube or capsule, after which the several parts of the apparatus are connected and the flask is heated on a water-bath until all the oil or grease has been extracted and dissolved by the petroleum ether. According to the form of apparatus employed, this may require from twenty minutes to one hour. The flask is then removed and the solvent is distilled off. The residual grease in the flask is then dried for one-half hour on the water-bath and after cooling weighed. The increase in the weight of the flask represents the amount of grease.

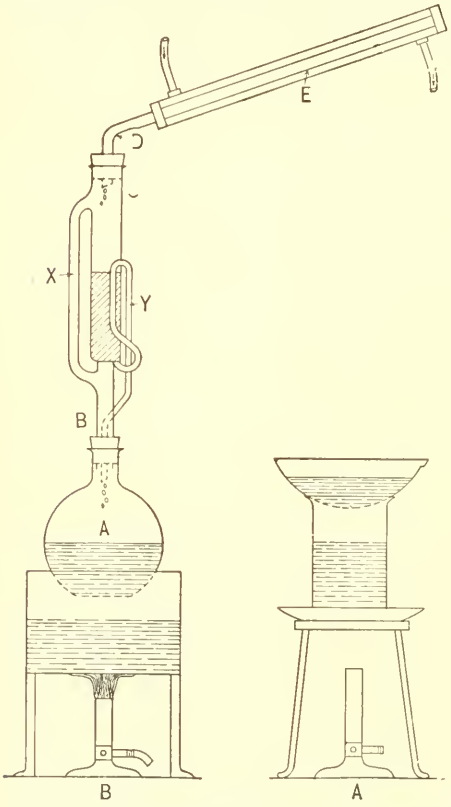

Fig. 409.—Apparatus for Testing Amount of Oil in Tops or Other Textiles.

E. W. Tetley (*Textile Manufacturer*) gives the following method for testing the amount of oil contained in worsted tops. A recognised standard for oil-combed tops is $3\frac{1}{2}$ percent by this test, 3 percent being added oil, $\frac{1}{2}$ percent being the natural fat contained. A flask of 500 cc.

capacity is taken, and 5 grams of top, carefully weighed, placed therein. Three hundred cc. of petroleum spirit is then poured into the flask, this quantity covering the material. It is left, say, a day, being shaken at intervals, the solvent during that time thoroughly absorbing all the fatty matter. Then 100 cc. is carefully poured off into an evaporating dish of known weight, the dish being placed over a water-bath and the spirit evaporated. The use of the water-bath is to evaporate the spirit at steam heat, and a handy way is to have the water in a beaker, and place the dish on top of it, the steam from the boiling water heating the dish sufficiently. The sketch (Fig. 409 A) shows the arrangement. After the solvent has quite evaporated, the dish is placed in a drying-oven at 100° F. for one hour, taken out, and allowed to cool. The dish and contents are then weighed, the increase in weight representing the total fat absorbed by the 100 cc. of solvent, which, multiplied by 3, gives total fat in 300 cc.—i.e., in the 5 grams of "top." The percentage may be then calculated thus:

Weight of evaporating dish..... = 54.52 grams
Weight of dish + residue after experiment..... = 54.57 "
∴ Weight of oil in 100 cc..... = 0.05 "
∴ Weight of oil in 300 cc., or in 5 grams of top. = 0.15 "
∴ Percent oil on top = $\frac{100 \times 0.15}{5}$ ..... = 3 percent

If a very accurate result is desired, the use of the Soxhlet apparatus illustrated (Fig. 409 B) is necessary. A flask (*A*) of known weight is taken and placed over a water-bath, the flask being about half-filled with ether. Through the cork of the flask is fitted the lower end of the extractor (*B*, *C*). Through the cork at the top of the extractor is fitted the tube (*D*) leading to the condenser (*E*) as shown. By means of retort stands the whole apparatus can be made quite firm. The material to be tested is weighed carefully and placed in the widened tube of the extractor (which is quite separate from the lower narrow tube) to about the height shown by the shaded portion. By means of a Bunsen burner, the ether is evaporated, the vapor passing up through the lower tube, then to the left through side tube (*X*), and thence into the upper portion of the extractor, from which it passes into the Liebig condenser. This condenser, being surrounded by a jacket of constantly changing cold water, condenses the vapor, which returns into the extractor thus, and drops down on to the material, through which it percolates, when, having become saturated with the fat, it finds an outlet in the syphon tube (*Y*). When the condensed ether in the extractor reaches to the height of the top of the syphon tube, it syphons over, passes down the tube, and returns into the flask in the manner shown. In this way the ether returns to the flask, having

on its way absorbed the fat from the material. The operation must be continued until the returning ether is pure, this resulting as a rule after it has syphoned over about ten times. The flask is then removed, the ether evaporated over a water-bath, and placed in the oven to dry until the weight becomes constant. The increased weight of the flask will give the amount of oil or fat which was contained in the sample, from which the percentage can be reckoned. It should be noted that the corks should not be of rubber, and should be free from grease and dirt, which may be extracted, if necessary, in ether.

7. Estimation of Finishing Materials on Fabrics.—Cotton fabrics are quite generally sized or otherwise finished for the purpose of giving the cloth a better handle or a greater weight. For this purpose a wide variety of substances may be used, but starch is nearly always the basis of the sizing. Soaps, fats, gelatine, vegetable mucilages, resin, and China clay are also of common occurrence. In some cases hygroscopic salts, such as calcium chloride, magnesium chloride, or zinc chloride are used to obtain certain effects or to increase the weight of the goods. Woolen goods are sometimes sized or weighted in a similar manner, both for purposes of reducing certain finishes and of fraudulently increasing the weight of the fabric.

Thompson [1] gives the following typical analyses of cotton fabrics:

	I.	II.	III.	IV.	V.	VI.
	Percent.	Percent.	Percent.	Percent.	Percent.	Percent.
Material:						
Fiber	47.29	53.02	60.75	70.84	80.51	81.78
Normal moisture	4.11	4.61	5.28	6.16	7.02	7.11
Weight of cloth	51.40	57.63	66.03	77.00	87.53	88.89
Dressing:						
Water	6.01	5.02	4.65	3.07	2.01	2.89
Dressing and fat	12.77	13.36	13.33	12.43	8.30	3.33
Mineral matter	29.82	23.99	15.99	7.50	2.16	4.89
Weight of dressing	48.60	42.37	33.97	23.00	12.47	11.11

According to Hoyer cotton cloth in the gray or unbleached state should consist approximately of 83 percent fiber, 7 percent moisture, 8.5 percent of starch and fatty matters (used for softening the yarn and sizing the warp), and 1.5 percent of ash. After boiling-out and bleaching, however, only 78 percent of fiber is left, so that by the addition of dressing

[1] *Sizing of Cotton Goods*, p. 150.

the finished cloth consists of 78 percent fiber, 7 percent moisture, 7 percent starch, and 7.5 percent mineral matter. If the amount of fiber falls below 78 percent in bleached calico or much below 83 percent in gray calico, it may be supposed that the cloth is loaded.

Linen fabrics should contain but a small amount of finishing or dressing materials. Usually a small quantity of starch is required for the purpose of sizing the warps, but no mineral matter should be present beyond that to be found in the natural fiber itself. Linen cloth should not lose more than 5 percent when boiled in water.

Woolen goods are often finished with Irish moss, glue, gelatine, dextrine, starch, albumen, sodium silicate, etc.

In the finishing of silk fabrics gelatine, tragacanth, gum arabic, shellac, etc., are used.

The following is a brief and general survey of the determination of finishing materials on textile fabrics:

(*a*) *Moisture* is determined in the usual manner as described above. If the amount of moisture is large a high degree of weighting or finish may be suspected, especially in the case of cotton goods, since starch absorbs much more water than the pure cotton fiber.

(*b*) *Benzene Extract.*—The dried sample is extracted in a Soxhlet with benzene. This will dissolve out fats, rosin, wax, paraffin, etc. The extract is distilled and the amount of solid residue determined.

(*c*) *Water Extract.*—The sample is then boiled in water for one hour, which will remove dextrine, starch, glue, gum arabic, sugar, Irish moss, tragacanth, etc., as well as various insoluble matters such as talc, China clay, etc., which are held on the fiber by the various finishes. The water extract is filtered, and the solution may then be examined for the various ingredients.

(*d*) *Mineral Matters.*—These may be determined by igniting a weighed sample of the fabric to a complete ash. The ash may further be tested in order to determine its various ingredients.

Prior gives the following method for testing the ash of textile fabrics: A portion of the ash is boiled with nitric acid and a strong effervescence will indicate the presence of metallic carbonates. The solution is evaporated to dryness on a water-bath, taken up with nitric acid and water, any insoluble residue filtered off, and the filtrate treated with hydrogen sulfide. A black precipitate will indicate the presence of lead. This should be filtered off, dissolved in nitric acid, and tested with sulfuric acid, potassium chromate or other reagents to confirm the presence of lead. The filtrate is tested for iron by neutralising with ammonia and adding ammonium sulfide. The filtrate from this precipitate is tested for barium, calcium, and magnesium by acidulating with hydrochloric acid, boiling to expel the liberated hydrogen sulfide, then neutralising with ammonia and

adding ammonium chloride and carbonate. Any precipitate is filtered off, washed, and dissolved in dilute hydrochloric acid and this solution is tested by the addition of calcium sulfate solutions. Immediate precipitate indicates the presence of barium. Another portion of this filtrate is tested with ammonium oxalate solution when a precipitate will indicate the presence of calcium. The ash which is insoluble in nitric acid may contain silica resulting from the decomposition of magnesium silicate or sodium silicate together with barium sulfate, tin oxide, gypsum, or clay. This residue is boiled with sodium carbonate which will dissolve the silicate and decompose the gypsum. After filtration, the precipitate is washed, dissolved in cold dilute hydrochloric acid and tested for the presence of iron and calcium as above indicated. The filtrate is acidulated with hydrochloric acid, evaporated to dryness, and the residue is taken up with water and hydrochloric acid. Any insoluble residue of silica is separated and the filtrate is tested for sulfuric acid by the addition of barium chloride. The residue which is undecomposed by sodium carbonate or insoluble in hydrochloric acid may contain barium sulfate, clay, or tin oxide. This is fused with 10 parts of sodium carbonate in a porcelain crucible and the melted mass is treated with water and sodium bicarbonate and filtered. The water residue is next boiled with strong hydrochloric acid and the liquid treated with hydrogen sulfide. A yellow precipitate will indicate the presence of tin. This is filtered off and half the filtrate is tested for aluminium by the addition of ammonia, and the other half for barium by the addition of sulfuric acid. The filtrate from the fusion is treated with hydrochloric acid and partially evaporated, which will throw out the silica. The soluble portion is tested for the presence of sulfates by the addition of barium chloride.

8. Analysis of Bleached Cotton.—In the bleaching of cotton the main object is to remove all impurities from the fiber, leaving only the pure cellulose as the resulting product without, however, disintegrating and weakening the structure of the fiber itself. In the processes of bleaching, alkalies, acids and strong oxidising agents are employed; hence there is danger of the formation of oxycellulose, a condition which must be avoided if good bleaching is to be attained. The physical tests which should be applied to bleached cotton are:

(1) **Color;** for which purpose a sample should be examined in a good north light and compared with a standard sample. There is no absolute standard of white; hence such a color test must be a comparative one.

(2) **Tensile Strength;** this should be determined with reference to both the unbleached and bleached samples, and any loss due to the process of bleaching is noted. This loss will naturally vary with the nature of the material being bleached. In the case of yarns, the tensile strength is generally somewhat less on bleaching, but the loss should not be over

5 percent when the bleaching is properly conducted. In the case of 2-ply yarns there is often no appreciable loss in strength due to bleaching. In bleached cloth the loss in strength due to bleaching, if any, should not be over 2 percent. In many cases there will be a noticeable increase in the strength of the cloth, due no doubt to a shrinking and felting together of the fibers.

(3) **Elasticity;** this factor is usually reduced to some extent by bleaching. This is especially the case where the material is stretched and pulled during the processes of bleaching and washing.

In this connection O'Neill gives the following interesting results, made to determine the tensile strength of cotton-threads before and after bleaching:

	Average Weight Required to Break a Single Thread.	
	Before Bleaching.	After Bleaching.
No. 1 cloth, weft-threads	1714 grains	2785 grains
No. 1 " warp-threads	3140 "	2020 "
No. 2 " "	3407 "	3708 "
No. 3 " "	3512 "	4025 "

It will be noticed that in two cases out of three the warp-threads are stronger than before, and it may be safely concluded that the tensile strength of cotton yarn is not injured by careful though thorough bleaching, and probably it may be strengthened by the wetting and pressure, causing a more complete and effective binding of the separate cotton fibers, the twisting together of which makes the yarn stronger.

The chemical tests to be applied in judging the quality of bleached cotton are as follows:

(1) **Ash;** this is best determined by taking 10 grams of the sample clipped into small fragments and burning in a porcelain crucible until a complete ash is left. The weight of the residual ash is calculated to a percentage on the weight of the sample taken. The ash of raw cotton will average about 1 percent; on boiling off, this amount will usually be reduced to about 0.25 to 0.35 percent; and a well-bleached cotton should not give more than 0.10 percent for yarns and light-weight fabrics, and 0.15 percent for heavy-weight fabrics. The manner and degree of bleaching, however, will have much to do with the amount of ash. Cotton which has been poorly boiled out and only partially bleached may show a much higher proportion of ash; or cotton which has been thoroughly bleached but not well washed, or which has been washed with

impure water, may also show in ash as high as 0.25 to 0.50 percent. Cotton which has been overbleached by the use of too strong a solution of bleaching powder will also usually show a proportion of ash greater than that which is allowed. The determination of the amount of ash is an excellent control-test in ascertaining the quality of the bleaching. A frequent defect in the bleaching of cloth and knit-fabrics is that caused by portions of the fabric coming in contact with strong solutions of the chemic, which is subsequently only incompletely removed. This results in a discoloration and weakening of the goods, though the defect may not become apparent until after the goods have been stored for some months. In all such cases the amount of ash will be abnormally high (from 0.25 to 0.50 percent).

(**2**) **Oxycellulose;** when cotton is bleached with solutions of chloride of lime there is nearly always more or less oxycellulose formed. This is also true when the cotton has been improperly boiled out previous to bleaching. The presence of oxycellulose to any considerable extent in bleached cotton fabrics leads to various defects, such as tendering of the fiber, discoloration and improper and uneven absorption of dyestuff if the fabric is subsequently dyed. There are a number of tests to show the presence of oxycellulose:

(*a*) As oxycellulose has a greater attraction for certain basic dyestuffs than ordinary cotton, by staining the fabric with dilute solution of Methylene Blue the presence of oxycellulose may be detected. In applying the test the sample should be well washed, treated for thirty minutes with cold dilute nitric acid (2° Bé.), again washed, treated with boiling sodium bisulfite solution (1° Bé.) for fifteen minutes, washed, treated with dilute hydrochloric acid (2° Bé.) for thirty minutes, and finally washed with water. The sample so prepared is then steeped for twenty minutes in a $\frac{1}{10}$ percent solution of Methylene Blue, rinsed and dried. Portions of the fabric which may contain oxycellulose will appear considerably darker in color.

(*b*) Ordinary cotton when treated with an iodine solution gives a yellow coloration changed to blue with sulfuric acid, but oxycellulose gives an immediate blue color which is destroyed by sulfuric acid.[1]

(*c*) A more satisfactory test for oxycellulose is to heat the fabric for fifteen minutes with 10 percent Fehling's solution on the hot water-bath. After rinsing with water, red cuprous oxide will be found deposited wherever oxycellulose is present. Before carrying out this test all sizing and finishing compounds should be removed from the sample. This test may be carried out in a quantitative manner, giving what is known as the "*copper index.*" Proceed as follows: 3 grams of bleached cotton are placed in a $1\frac{1}{2}$ liter flask, and 300 cc. of boiling water and 50 cc. of

[1] Vétillart, *Bull. Soc. Ind. Rouen*, 1883, p. 233.

Fehling's solution added. The mixture is boiled for fifteen minutes, using a reflux condenser so as to avoid loss of liquid. Then filter and wash until the wash-water is free from copper salts. The cellulose remains on the filter with the precipitate of cuprous oxide. This is treated in a porcelain dish with 15 cc. of nitric acid. The dissolved copper is filtered off, and its amount may be determined by electrolysis, or quantitatively by the usual methods. This amount of copper calculated to percentage on the amount of cotton taken for analysis gives the copper index, and measures the amount of oxycellulose and hydrocellulose present.[1] In carrying out this test the use of cork or rubber stoppers should be avoided, as these will cause the precipitation of red cuprous oxide. The apparatus used should have ground glass joints.

(*d*) The sample is treated with a dilute solution of Benzopurpurine, then rinsed with dilute sulfuric acid, and finally washed with water until the red color of ordinary cotton reappears. Any portions containing oxycellulose will remain as bluish black stains.

(*e*) Vieweg makes a determination of what is termed the *acid index*, as follows: 3.2 grams of the dried bleached cotton are boiled for fifteen minutes with 50 cc. of a semi-normal solution of caustic soda. The excess of soda is then titrated with a semi-normal solution of sulfuric acid using phenolphthalein as the indicator. The amount of caustic soda neutralised by the cotton calculated to a percentage basis gives the *acid index*, and represents the alkali neutralised in decomposing and dissolving the hydrocellulose and oxycellulose present in the bleached fiber. Piest [2] has compared this method with that of the copper-index method of Schwalbe, and concludes that the latter factor is preferable as an accurate indication of the amount of oxidised cellulose present in bleached fabrics.

(*f*) Another test for oxycellulose which is said to be very reliable is as follows: A few drops of a suspension of Indanthrene Yellow (prepared by dissolving some of the dried paste of the dyestuff in strong sulfuric acid, precipitating by pouring into cold water, and neutralising) are added to a 10 percent solution of caustic soda, and the fabric to be tested is passed through the mixture and slightly squeezed. The material is then held over a beaker in which water is vigorously boiling. Within a minute a deep blue stain appears wherever oxycellulose or hydrocellulose is present, while the rest of the fabric, if it has been carefully bleached, shows no trace of blue for at least five minutes. If the cotton is next washed, soured, and scoured with soap, the unaffected dye is readily removed, but wherever oxycellulose has formed the color is firmly fixed.[3]

According to Nanson the yellowing of bleached canvas may be due to the effect of heat or time on (*a*) oxycellulose, (*b*) chloramines formed by

[1] Schwalbe, *Zeit angew. Chem.*, 1910, p. 924. [2] *Zeit. angew. Chem.*, 1910, p. 1222.
[3] Scholl, *Berichte*, 1911, p. 1312; and Ermen.

the action of chlorine on the albuminoids of imperfectly scoured cotton, or (*c*) the chloramines accumulated in old bleaching liquors.

The following chemical methods have been proposed for the purpose of estimating in a practical manner the extent to which cotton has been bleached. These analytical methods serve as a basis of estimating the chemical condition of the bleached fiber, and many times may form a valuable means of detecting overbleaching and the presence of decomposed cellulose.

(1) The so-called " wood-gum value " represents the substance soluble in a 5 percent solution of sodium hydroxide when the cotton is left in contact with the solution for a considerable time and without heating. This " wood-gum value " is a complex function, and includes small quantities of fats and fatty acids, gums, and a portion of the products of overbleaching. The latter may be classified as oxycellulose. The multiplicity of the factors in this value deprives it of the character of an absolute analytical number, but it serves as an aid to determine the purity of the bleached cellulose. In the case of normally purified cotton this " wood-gum value " lies between 0.5 and 1.1 percent.

(2) The " copper value " represents a standard suggested by Schwalbe, and is perhaps the most definite measure available for the diagnosis of the presence of any chemical modification in the cellulose, and particularly is it indicative of over-bleaching. Normally purified cotton shows a total " copper value " considerably below 2, and in general it is preferable that this value should not exceed 1; whereas the " copper value " of strongly over-bleached cotton may rise to as high a figure as 16. Hydrocellulose likewise shows an increased " copper value," but not nearly to the same degree as is the case with oxycellulose.

(3) The " copper hydrate value " represents the quantity of cupric hydroxide absorbed by the bleached cotton from a cold Fehling's solution. This is regarded as indicating the state of hydration of the cellulose, and consequently is especially pronounced in the case of mercerised cellulose. It is normal (that is to say about 0.5) in the case of oxycellulose, and particularly low in the case of hydrocellulose.

(4) The " acid value," which has been described by Vieweg, represents the amount of caustic soda which is neutralised by the bleached cellulose after boiling for one-half hour with a 1 percent solution of sodium hydroxide. This is also a complex function and indicates primarily the chemical modification in the fiber due to the formation of oxycellulose and hydrocellulose in approximately equal degrees, and consequently it indicates the specific susceptibility of the bleached cellulose itself to the action of alkaline hydrolysis. This value is particularly low in the case of cellulose which has already been treated with a solution of strong caustic soda, such, for instance, as is the case with mercerised cotton, and which is not otherwise modified by any strong oxidising or acid treatments which

would increase the tendency of the cellulose in the fiber to undergo hydrolysis.

(5) The " copper sulfate value " is the quantity of cupric hydroxide absorbed by the bleached fiber from a solution of copper sulfate. This value has but little diagnostic importance;. it tends to be low in the case of oxidised cellulose, but the differences between this and normal cellulose are really too small for any practical use.

(6) The " viscosity test " of Ost is a most valuable measure of the chemical condition of the bleached fiber, but in the case of chemically modified cellulose it shows no distinction between the various causes of this modification. The test is made by treating the bleached cotton in a solution of cuprammonium hydrate prepared in the manner described by Ost; this cuprammonium cellulose solution is then diluted with water in a certain prescribed manner and, after standing for five days, it should show a viscosity of about 10 in the case of normally treated cotton. Mercerised cotton will also show normal viscosity, but the prolonged action of a mercerised alkali solution will modify the cellulose as strongly as will the action of strong oxidising agents and acids, and this modification will considerably affect the figure for viscosity.

Ambühl [1] gives the following method of ascertaining whether bleaching has been carried out efficiently and in such a manner as to preclude the possibility of the goods turning yellow: (1) The free fat (ether extract) is estimated by extracting 15 to 18 grams of material with ether in a Soxhlet apparatus, and weighing the residue; bleached fabrics giving more than 0.4 percent of ether extract should be rejected; (2) the lime soaps (combined fatty acids) are determined from the sample just extracted with ether by steeping for thirty minutes in a 5 percent solution of hydrochloric acid, washing, drying, and again extracting with ether in a Soxhlet. The fatty acids thus extracted are dried, dissolved in warm alcohol, and titrated with N/20 caustic soda solution, using phenolphthalein as an indicator; well bleached cloth should not contain more than 0.08 percent of fatty acids; (3) the ash is determined in the usual manner, and well-bleached goods should not contain more than 0.05 percent of ash. In most cases the amount of ash corresponds to the amount of lime soap present. In these tests, of course, it is to be understood that the sample has not been treated with any loading or sizing or softening materials. The following examples show the results of such tests:

	Free Fat, Percent.	Fatty Acids, Percent.	Ash, Percent.
Gray cloth	1.0448	0.1359	1.6294
After boiling with caustic soda and soda ash.	0.1761	0.4923	0.2230
Bleached	0.0210	0.0433	0.0571

[1] *Chem. Zeit.*, 1902.

Knecht [1] has made a study of the action of prolonged heat on bleached cotton. The bleached cotton material was heated in a water-jacketed air bath at 80° to 100° C. for periods up to 530 hours. The air-dried material was exposed in test-tubes sealed with a blow-pipe, or on open watch-glass faces. It was found that bleached cotton yarn and cloth exposed on watch glasses remained unchanged the first few days, but soon after changed slowly to a grayish-brown color. After 336 hours the strength had decreased 33 percent, and tests also showed the formation of some oxycellulose. Cotton yarn exposed in tubes changed more rapidly after 336 hours. When the tubes were broken under mercury they showed a slight vacuum equal to about one-fifth the height of the tube, indicating that oxygen had been absorbed, and the strength of the yarn had decreased about 50 percent.

9. Testing Waterproof Fabrics.—In testing fabrics for waterproof qualities the common method is to pour a quantity of water on to a pouch in the cloth.[2] The cloth should be able to stand rubbing underneath and should show no trace of wetness when the water is moved about over the surface of the cloth. This test is valueless when it is desired to make a comparison between different processes or when new processes are being tried on an experimental scale, say, with pieces of cloth 6 by 6 ins. A common method is to make a pouch with a piece of cloth by stretching it on a suitable frame.

The under side of the cloth should show no appearance of dampness after two or three days. Another good method is to take about 6 by 6 ins. and fold it twice like a filter and place in a suitable glass funnel. A definite volume of water is measured into it, and at the end of twenty-four hours nothing more than a few equally distributed drops of water should be perceptible on the under side. A good cloth will not show any drops on the under side for days.

In Germany the following test is prescribed for sail-cloth: A sample of the cloth 10 ins. square is folded like a filter-paper and placed in a suitable glass funnel where 300 cc. of water are poured upon it and it is

[1] *Jour. Soc. Dyers & Col.*, vol. 36, p. 195.

[2] *Points to be Considered in the Preliminary Examination of the Material.*—One of the simplest and at the same time most useful tests is to hold a generous sample of the material between the inspector's eye and a brightly lighted window. A surprisingly great number of samples from supposedly high-grade material will show numbers of pinholes, uncoated spots, reed marks, etc. In no case has it been found as the result of tests that material which showed pinholes resisted the passage of water satisfactorily. It has been stated that the treatment would so increase the tendency of the cloth to resist wetting that water would not go through small holes. This theory does not serve to protect holes which may be seen through in this way. The finished cloth should not have an objectionable odor, or be greasy, or very stiff. The coating should not rub off or dust off, nor crack on sharp creasing, nor should it make the cloth tacky. The color should be even and attractive for the purpose.

left for twenty-four hours. At the end of this time only a few equally distributed drops of water should be discovered on the under surface of the cloth, and the fabric should not be wet through.

The U. S. War Department gives the following specifications for the quantitative testing of rainproof and waterproof cloth:

(1) *The Drop Test.*—This is a test which furnishes a numerical value representing degree of waterproofing under conditions approximating more or less to rain. The sheet of cloth is laid upon blotting paper on a glass plate, supported at an angle of 45°. Beneath the plate is a horizontal mirror. Water is dropped 5 ft. from a burette on to the cloth at the rate of 20 drops a minute, and this is continued until the water passes through the cloth and stains the blotting paper, which can be viewed in the mirror, and the number of drops required thus determined. Considerable variations occur between the minimum and maximum drop numbers, but the average of twenty trials is regarded as characteristic. An average of 6.4 drops is obtained in a cloth sufficiently impermeable for most purposes, while 15 drops represent a very good class of cloth. To pass the War Office test, however, 60 drops are required. The cloth should be tested again after rinsing in cold water and drying, or, for a more severe test, soaking in water twenty-four hours and drying. The cloth should also be ironed while covered with a damp cloth, and again tested.[1]

(2) *The Dash Test.*—Water is poured on to the cloth, which is held horizontal meanwhile. A test of no particular value.

(3) *The Trough Test.*—The cloth is suspended by its four corners and 500 cc. of water poured in. It is of little use, except as a test for holes, owing to the length of time required.

(4) *The Filter Test.*—Widely used in the trade, but not nearly so good as the drop test. It is, however, useful for detecting pinholes. A square piece of cloth of 10 ins. side, is folded like a filter paper, and placed in a glass funnel of 60°, with 300 cc. of water inside. After twenty-four hours the stuff should not be wet through. A good modification is to fasten a piece of cloth over a thistle funnel, invert it, fill with cold water, and support for ten hours over a graduated cylinder. Cloth which allows no water to pass in ten hours is considered excellent.[2]

[1] Many firms make use of the dropping tap for testing their waterproof goods. A bottle or cistern is fitted with a dropping tap to allow drops of water to fall at regular intervals. A wooden frame is inclined at an angle of 45°. One edge of the cloth to be tested is fastened to the uppermost edge of the frame, and the cloth allowed to fall over, the bottom edge being kept taut by means of a bar to which the bottom edge of the cloth is fastened. The drops of water are allowed to drop on the center of the cloth. At first they run down the incline, but after some time elapses, say from one to five hours, according to the quality of the waterproof, the drops begin to go through the cloth. The time elapsing before this occurs is taken as the value of the proofing. According to the height the water has to fall, minute drops will spray through the interstices, but the water does not collect to form a drop for a considerable time.

The dropping test may also be carried out as follows: The cloth is extended beneath the dropping tap and a piece of blotting paper placed underneath the portion of cloth where the drops will fall. Sixty drops are allowed to descend from an elevation of 6 ft. and if the blotting paper shows no wetness after the test the cloth is considered satisfactorily proofed.

[2] The thistle funnel forms a convenient and excellent means for the comparative testing of waterproof fabrics. A portion of the cloth is tied firmly on to the thistle end,

Gawalowski describes an apparatus for determining the waterproof qualities of a fabric as follows: The sample of the cloth is attached to the open end of a graduated tube (a burette will serve the purpose, using the large opening for the cloth), which is then filled with a column of water 12 ins. in height. At the end of twenty-four hours an observation is made as to how much water has passed through the cloth.

Another method of testing which is of value in differentiating between good and useless waterproof canvas is to take a piece of the fabric and fold it into a pocket, placing a variety of heavy articles in the pocket, and immerse as far as possible in water. A good fabric should not wet through in twenty-four hours.

Tulle and similar fabrics can be so prepared that they will not be spoiled by rain, and can be cleaned with a wet sponge. This is done by impregnating the material with an ordinary solution of collodion, to which enough amyl acetate has been added to make the drying slow. The tulle, after treatment, has a soft handle and ample luster. The coating does not peel off. Gum-lac is added with advantage. One recipe in the specification [1] is as follows: 6 kilos. of gum-lac is dissolved in 4 liters of spirit and 16 liters of amyl acetate. After complete solution the liquid is mixed with 13 liters of collodion.

W. Borks [2] uses a mixture of ceresin, Venice turpentine, paraffin, and crude rubber for waterproofing, especially for coarsely woven fabrics or nets. The recipe is as follows: Melt together 375 lbs. of ceresin, 400 lbs. of Venice turpentine, and 150 lbs. of paraffin wax, and then stir in a thick solution of 3 lbs. of unvulcanised India rubber. The rubber does not contribute much to the waterproofing, its function being rather to bind the other ingredients on to the fiber. It is claimed that this composition not only perfectly waterproofs the fabric, but improves its resistance to wear.

and the funnel fixed in an inverted position in a clamp. By means of a wash bottle the globe part is filled with water. This will represent about 1 in. pressure and any cloth if at all waterproof will stand this. With a pipette the pressure of water is gradually increased, the water level mounting up the stem of the funnel. One should be able to increase the pressure until it is sufficient to force drops between the interstices. The level in the stem of the funnel now falls some distance when it remains constant and will stay so for days. The height of the water is measured and may be taken as indicating the degree of "proofing." Anything above 2 ins. of water is quite good. The underside should not become wet and the water when forced through by the pressure should be in evenly dispersed drops. It is also possible to get figures by filling up to a certain height for each test, and measuring the time elapsing before the first drop appears on the underside or the amount of water passing through in a certain time, say ten hours. More elaborate modern testing apparatus is very similar to the foregoing in principle. A column of water is allowed to act on the test sample and the water passing through in a given time is measured. In one such apparatus a graduated burette has its lower extremity closed with an attachment resembling a polarising tube, but instead of the glass disk found in such tubes the sample of cloth is cut to correct size and fitted in. A slanting outlet is cut through the metal attachment and a small measuring flask placed underneath. The burette is filled up to the zero mark, and the amount of water falling through in twenty-four hours collected.

[1] *Ger. Pat.* 258,471. [2] *Ger. Pat.* 275,659.

Wosnessensky [1] describes an apparatus recommended for the testing of waterproof cloth. It consists of a cylindrical copper box (see Fig. 410) to which are attached a glass measuring tube and a rubber bulb. On the top of the box are fixed, by means of two screws, two rings, one of copper and the other of rubber. At the beginning of the test the box is filled with water, and on the top is fixed a piece of the cloth to be tested. By pressing the bulb the height of the water in the glass tube rises and measures the pressure within the box. When this becomes sufficiently small, drops of water will be observed on the surface of the cloth. The height of the water column measures the degree of impermeability of the sample.

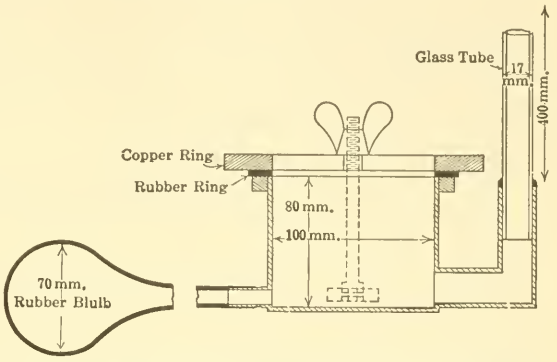

FIG. 410.—Wosnessensky's Apparatus for Testing Waterproof Quality of Fabrics.

Heermann described several methods of testing waterproof fabrics as follows:

(1) *Bag Test.*—A square of the fabric, 50 by 50 cm. or 100 by 100 cm. is tied with strings by the four corners to a frame in such a way that a bag is formed. The bag is filled to a given height with water at the temperature of the room. The height of the column of water used varies, depending on the uses to which the fabric is to be put. No dropping or trickling through of water should take place in twenty-four hours, but sweating through or transudation is permitted. Uniform cloth, tent cloth, fabric for knapsacks and bread bags were tested by this method, using pieces 50 cm. square, filled with water to a depth of 75 mm. After twenty-four hours the water may sweat through but should not drip through. The specifications for wagon covers for the Prussian State Railway prescribed that a piece 100 cm. square should be used and that the depth of water should be 10 cm. After twenty-four hours there should be no dripping. Heermann considers one test as usually sufficient, but in certain circumstances the same piece is dried and tested for a second or third time, in order to determine how the fabric stands wear.

(2) *Spray Test.*—A piece of cloth 50 by 50 cm. is weighed after having been exposed to 65 percent relative moisture for several hours. It is then spread out smoothly on a frame and set up outdoors in a slanting position. A sprinkling apparatus connected with the water supply is set up at a distance of 6 to 10 meters from the cloth, and the nozzle is arranged so that a fine spray strikes equally all over and falls from a height of 2 to 3 meters. The under surface is examined from time to time for penetration of water. If the water has not penetrated the spraying is continued. Whether, and at what time, water appears on the under side during the spraying is

[1] *Jour. Soc. Dyers & Col.*, 1915, p. 50.

also observed. At the end of an hour the spraying is stopped, the materials is hung up to dry for five minutes and weighed. It is claimed that the smaller the amount of water absorbed the more efficient is the waterproofing preparation. Duplicate or triplicate tests are made.

Villavecchia describes a spray test in which the fabric is inclined at an angle of 25 degrees and water allowed to drip upon it for three hours from a height of two meters at a rate of 31 per minute on the central part of the fabric so as to cover an area of 3 cm. in circumference. At the end of the experiment no water, or at most a minimum quantity, should have penetrated the fabric.

Veitch and Jarrel [1] after an exhaustive comparison of the different methods for testing waterproofed fabrics devised the following methods:

Modified Funnel Test.—Cut a piece of the fabric 1 ft. square, weigh, crumple thoroughly in the hand and place in an 800-cc. beaker and soak in distilled water at from 70° to 80° F. for twenty-four hours, removing, straightening out and recrumpling four or five times during this period. Remove from the water, straighten out and dry in oven at 45° C. for twenty-four hours, and hang in laboratory overnight. Crumple, resoak in distilled water, and dry at 45° C. for twenty-four hours, and hang in laboratory overnight as before. Again crumple, smooth out and place on a piece of absorbent paper (paper towelling) of the same size and fold the two together into the form of a filter, insert in a 6-in. glass funnel having an angle of 60°, and place the funnel in a support over a 500-cc. graduated glass cylinder and fill the funnel to a depth of exactly 4 ins. with distilled water of 70°–80° F. This depth equals 500 cc. of water. Maintain a constant water level above the funnel by inverting an Erlenmeyer flask filled with water and closed with a rubber stopper through which passes a glass tube ground at the end to an angle of 45°.

Make the following observations:

1. The time elapsed before the paper begins to wet.
2. The time elapsed until the paper is entirely wet.
3. The time elapsed before the first drop passes into the cylinder.
4. The quantity of water in the cylinder in one, three, six and twenty-four hours.
5. The time and extent to which the fabric becomes wet above the water level.

At the expiration of twenty-four hours, if there has been no dripping, the funnel filled with water is lifted 2 ins. and allowed to drop into its support; this is repeated four times and the amount of water that drips through in three hours, if any, is recorded.

Remove the funnel from its support and carefully pour and drain off the water, and then remove the fabric and paper from the funnel, smooth out and observe:

1. Whether the paper is dry, damp or wet.
2. Whether the fabric on the outside is dry, damp or wet, or whether the water has only sweated through.[2]

[1] *U. S. Bureau of Chemistry.*

[2] The water-resistance of fabrics as determined by this method is rated in accordance with the following scale:

Very High 10.—The fabric does not become wet above the water level within twenty-four hours. No water drips through. No sweating through is apparent

Modified Spray Method.—Dry the piece of fabric used in conducting the funnel test at 45° C. for twenty-four hours, hang in laboratory overnight and clamp loosely in a frame. Set the frame in a holder attached to a trough at an angle of 45°. The trough used held six frames. Allow clear tap water at room temperature to fall from a height of 6 ft. upon the central portion of the fabric, covering an area of about 8 ins. in circumference, for twenty-four hours, from a $2\frac{3}{4}$-in. brass spray nozzle having 25 holes, each 1.9 (0.75 in.) mm. in diameter, at a rate of 1000 cc. per minute.

Inspect the condition of the under-side of the fabric at the end of five minutes, one-half hour, one hour, three hours, seven hours, and twenty-four hours. Note at each inspection whether the under surface is dry, damp or wet with no dripping; damp or wet with dripping.[1]

except to a very limited extent at the folds. Filter paper under the fabric remains dry, except for slight wetting where the fabric is folded.

High 9.—The fabric does not wet above the water level within twenty-four hours. Sweating through is sufficiently rapid to cover generally, and especially in the fold, the outside of the fabric with droplets. Filter paper under the fabric becomes wet.

High Medium 7 and 8.—The water dripping through: In six hours is from 1 cc. to 5 cc. In twenty-four hours is from 1 cc. to 25 cc. In three hours after raising and allowing the funnel to drop into support five times.

Medium 5 and 6.—The water dripping through: In six hours is from 5 to 25 cc. In twenty-four hours is from 25 to 50 cc.

Medium Low 3 and 4.—The water dripping through: In six hours is from 25 to 75 cc. In twenty-four hours is from 50 to 150 cc.

Low 1 and 2.—The fabric wets above the water level readily. The water dripping through: In six hours is from 75 to 200 cc. In twenty-four hours is from 150 to 300 cc.

Negligible 0.—The water dripping through in twenty-four hours exceeds 300 cc.

[1] The water-resistance of fabrics as determined by the modified spray test is rated on a scale of ten as follows:

10. Under surface of fabric remains dry for twenty-four hours.

9. Under surface remains dry for seven hours but is damp or wet in twenty-four hours. No dripping.

8. Under surface remains dry for seven hours but is damp or wet in twenty-four hours. Dripping.

Under surface remains dry for three hours hours but is damp or wet in seven hours. No dripping.

7. Under surface remains dry for three hours but is damp or wet in seven hours. Dripping.

6. Under surface remains dry for one hour but is damp or wet in three hours. No dripping.

5. Under surface remains dry for one hour but is damp or wet in three hours. Dripping.

4. Under surface remains dry for one-half hour but is damp or wet in one hour. No dripping.

3. Under surface remains dry for one-half hour but is damp or wet in one hour. Dripping.

2. Under surface remains dry for five minutes but is damp or wet in one-half hour. No dripping.

1. Under surface remains dry for five minutes but is damp or wet in one-half hour. Dripping.

0. Under surface damp to dripping in five minutes.

The spray test appears to check better with the results obtained by exposure to an actual rain than the funnel test.

The MacIntosh apparatus for testing the waterproof quality of fabrics is shown in Fig. 411. The cloth to be tested is cut in the form of a square and inserted in the apparatus so that it is pressed firmly against the open under side of the small pressure cylinder. A couple of inches of water are then allowed to flow into the latter and then pressure is gradually applied, the degree of which is shown by the reading on the manometer. A mirror placed beneath is used to observe the behavior of the fabric. The maximum water-resistance of the fabric is determined by reading the the pressure when the first drop of water has penetrated the cloth. For comparison it is said that the heaviest rain does not exert a pressure of more than 12 ins. of water.[1]

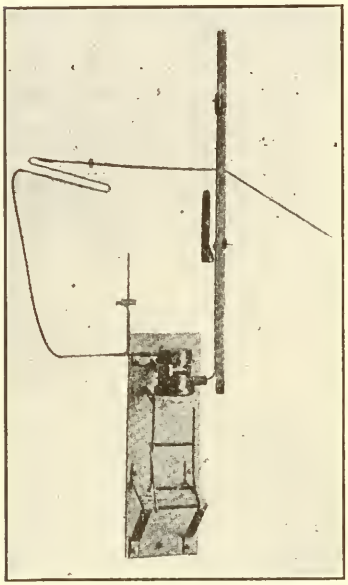

Fig. 411.—MacIntosh Apparatus for Testing Waterproof Fabrics.

10. Testing the Liability of Waterproofed Fabrics to Spontaneous Combustion.—In the waterproofing of fabrics the materials employed to render the goods waterproof may often introduce the risk of their becoming spontaneously inflammable. Oils that readily absorb oxygen if used in large amount upon a fabric may readily cause the development of sufficient heat to set fire to the goods. While mineral oils are free from this objection, they afford a ready fuel, and their vapors aid in the actual starting of the flame. In waterproofing compositions the chief danger arises from the use of linseed oil which while alone is readily sensitive to oxidation and consequent heating, has this liability increased by the use of materials on the fabric which promote its absorption of oxygen. Thus by the presence of true oxidants, catalytic agents of oxidation and the porous character of the oiled material, grave risk is at times encountered of the complete destruction of the goods. This is more likely to happen during the waterproofing of the material or soon after.

While in the operations of waterproofing with oils known to be of an oxidising nature, certain rough tests are made from time to time to control the product and to guard against the risk of inflammability, there is grave lack of a standard method of testing these fabrics, or such tests as are employed fail to indicate with definiteness whether the fabric will

[1] *Color Trade Journal*, 1922, p. 5.

be safe. For this purpose no instrument is better than the Mackey apparatus for testing the liability of oils to spontaneous combustion.[1] This has been found by frequent tests superior to other types of apparatus having the same end in view.

The apparatus consists of a cylindrical water-jacketed metal oven of the following dimensions: Outside 8 ins. high and 6 ins. in diameter; inside 7 ins. high and 4 ins. in diameter. The vessel is sealed with a lid lined with non-conducting material and having three holes, one at the center for a thermometer, and two diametrically opposite near the rim which receive copper tubes of $\frac{1}{2}$-in. diameter so arranged that when the lid is in place, one tube enters the oven to a depth of 6 ins., while the other rises to an equal height above the lid. These tubes assure a constant draft of air through the instrument. In common vertical axis with the central hole there is supported within the oven a cylinder of wire gauze 6 ins. long and $1\frac{1}{2}$ ins. in diameter. The fabric which is suspected of liability to spontaneous inflammability is placed in a finely chipped condition within the cylinder occupying the upper $4\frac{1}{2}$ ins., and the thermometer is so arranged that the bulb is in the center of this mass. The water is brought to the boiling-point and the cylinder and thermometer are introduced, the latter protruding through a cork placed in the central hole in the lid. The boiling temperature is maintained and the thermometer is read at the end of the hour and every fifteen minutes thereafter; noting, however, if between these times a maximum of rise is reached. The cylinder may be dispensed with if a piece of the fabric $4\frac{1}{2}$ by 36 ins. be wrapped directly about the thermometer. If the fabric tested attains a temperature of 100° C. within an hour, or if it reaches a temperature of 120° C. within an hour and a half, it must be considered as dangerous.

11. Testing Waterproofed Fabrics for the Effect of Extremes of Climate.—The testing for the effect of extremes of climate is of especial importance. It does not seem unreasonable to expect the material to withstand temperatures of 120° F. and 0° F. as maximum and minimum. The effect of heating can be readily determined by the use of an oven. The effect of cold is harder to obtain. Clark makes a freezing mixture of salt and shaved ice, and obtains an approximation of 0° F. in this way. The paraffined cloths will frequently be found to be very brittle at the lower temperatures, while some of the substances used will be very sticky and even volatile at the higher temperature. The heating should be continued for at least eight hours, and test for waterproof value made on the sample after heating. The aging effect of sunlight must also be considered, and where practicable it is advisable to expose the samples to the light from a dye-fading mercury or arc lamp for forty-eight to

[1] *Jour. Soc. Chem. Ind.*, 1896, p. 90, and 1907, p. 185.

seventy-two hours. Some fabrics will lose completely their waterproof value as a result of this exposure.

12. Testing the Durability of Fabrics.—It has generally been the practice to test fabrics by obtaining the tensile strength of warp and filling, but this method does not accurately measure the actual durability or wearing qualities of the cloth. Kertesz has devised the following method: Cuttings of cloth 23 cm. long (warp direction) and 32 cm. broad (filling direction) are treated for three-quarters of an hour at 94° C. with 10 percent of hydrochloric in a liquor forty times the weight of the cloth. The cutting must not be folded during the treatment. It is rinsed with distilled water till almost neutral, squeezed and extracted in a Soxhlet apparatus with 400 cc. of alcohol for an hour and a half. The samples are then squeezed, rinsed, and squeezed again, followed by drying for two hours at 70° C. After drying they are kept for at least half an hour in an oven at 25° C. before scraping tests are made. The cuttings are divided into six strips, each 5 cm. broad, and these strips are stretched singly in the jaws of the scraping machine, three being scraped on the face and three on the back. The testing is done comparatively with some standard cloth, the relative figures being given by the number of revolutions required before the cloth tears. Scraping rollers provided with engraved flutes proved best suited for the purpose.

13. Testing Permeability of Balloon Fabrics.—A method for conducting this test is given by Edwards and Pickering[1] as follows: The fabric which is to be tested is firmly held between the two halves of a circular metal cell, which is divided thereby into two chambers. A current of pure dry hydrogen gas is passed through one chamber so that one surface of the fabric is maintained in an atmosphere of hydrogen under a pressure of 30 mm. of water above the pressure on the opposite side, and a current of dry carbon dioxide gas is passed through the other chamber. The cell is suspended in a constant-temperature bath maintained at 25° C. The hydrogen which penetrates the fabric is swept by the carbon dioxide into a bulb containing caustic soda solution. The residual gas in this bulb will consist of hydrogen together with traces of air originally present in the carbon dioxide, and is passed into an explosion burette, where the hydrogen is determined.

14. Testing the Heat-retaining Value of Fabrics.—A number of devices have been suggested for testing the permeability of fabrics to heat with the idea of determining their heat-retaining values for clothing. The German Testing Bureau recommends the following: A copper flask having a flat bottom of 5.5. cm. diameter is surrounded by cotton and an insulating casing, and rests on a piece of felt on a wooden block; 200 cc. of hot water are placed in the flask and heated by steam until a temperature

[1] *Jour. Ind. Eng. Chem.*, 1919, p. 966.

of 100° C. is reached when the junction of a thermo-electric couple is placed between the flask and the piece of felt and the temperature noted at two-minute intervals for ninety minutes. The test is repeated with a sample of the material under examination between the bottom of the flask and the felt. The tests did not indicate the existence of any relation between the "heat-protection value" of the fabric and its nature, thickness, density, and other qualities, and the test is therefore only relative.

CHAPTER XXVIII

ANALYSIS OF FIBERS AND YARNS IN FABRICS

1. Microscopic Analysis of Fabrics.—Höhnel describes the following method employed for a microscopic examination of textile fabrics, where the object is to determine not only qualitatively the character of fibers composing them, but also their quantitative amounts. With regard to the preliminary qualitative examination, there are generally only a few fibers to be taken into consideration, as there seldom occur in the same fabric more than one to four different kinds of fibers. As a rule, the only fibers which will be found are cotton, linen, hemp, jute, ramie, sheep's wool, goat-hair, cow-hair, angora, alpaca, cashmere, llama, silk, and tussah silk. In woolen material there are also cosmos and shoddy to be considered.

To undertake the examination, cut off a sample of the material 2 to 3 sq. cm. in size, and separate this into its warp- and filling-threads. The sample must be of sufficient size to include all of the different kinds of yarns employed in the weave. Consequently, in the case of large patterns, it has to be rather large. The warp- and filling-threads are laid next to each other, and one of each kind is selected to serve for further examination. In the simplest case there is only one kind of warp-thread and one kind of filling present, which necessitates, therefore, the examination of only two different yarns. In complicated cases there may be as many as ten, or even more, different yarns to analyse. In woolen fabrics there will frequently be found yarns which are composed of two or three different threads twisted together; these must be untwisted and each separate yarn examined by itself.

In order to attain satisfactory results, the operator must be sufficiently skilled in the microscopy of the fibers to be able to recognise with certainty, under a low magnification, the different fibers liable to be found. By a low magnification is meant one of fifty to sixty times. A much higher power cannot be used in the examination of fabrics, for hundreds or even thousands of fibers have to be taken into consideration. From ten to twenty fibers, or perhaps more, should be obtained in the field at the same time, and it is necessary to be able to promptly recognise the different ones. With a higher magnification, it is true, the single fibers can be better recognised, but the general view is then lost, and there is danger in overlooking whole bundles of fibers. If the observer finds a fiber which

cannot be recognised with sufficient accuracy by means of the low power, it is a simple matter to so change the objective as to increase the magnification to allow of the necessary observations to be made, and then to proceed again with the examination under the lower power.

Dark-colored material often consists for the most part of threads which, on microscopic examination, appear quite opaque, hence dark and structureless. Therefore it will frequently be necessary to remove the dyestuff, at least in part, which is usually done by boiling in acetic acid, hydrochloric acid, dilute caustic alkali, potassium carbonate, etc., until sufficiently light in appearance.

In the case of very accurate examinations, each different kind of thread must be examined separately, and the number of fibers composing it, together with their kind and color, must be noted. In order to show the detail and scope of such an examination, the following example is given: On unravelling a sample four different warp-threads and one filling-thread were obtained. One of the warp-threads was composed of two yarns twisted together one of which was black (K_1a) and the other white (K_1b). Two warp-threads were dark blue (K_2 and K_3) and the fourth was a gray mix (K_4); the filling-thread (E) was blue. On examination the following results were obtained:

K_1a showed 85 shoddy fibers (mostly black, some yellow and red and even isolated green fibers of wool and 13 cotton fibers).

K_1b showed 31 pure white wool fibers.

K_2 and K_3, respectively, showed 46 and 53 pure blue wool fibers.

K_4 showed 60 shoddy fibers, of which 32 were mostly gray or black wool fibers, and 28 were gray cotton fibers.

E showed 60 blue wool fibers.

Therefore in this sample, including 4 warp- and 4 filling-threads, there would be $85+31+46+53+60=275$ single-warp fibers; and $60\times4=240$ filling fibers; or 515 single fibers altogether. Of these 31 were cotton, which were found in the shoddy, the latter comprising 145 fibers in all. Hence in a sample of this piece of goods containing equal lengths of warp and weft, there are 41 cotton fibers, 104 shoddy wool fibers, and 370 pure wool fibers, from which the respective percentages would be:

	Percent.
Cotton	8.0
Shoddy wool	20.2
Pure wool	71.8
	100.0

This, of course, only gives the relative percentages of the number of fibers; if it is desired to reach an approximate idea of the proportions by weight, then micrometric measurements must be made of the wool and cotton fibers occurring in the sample. In consideration of the fact that wool possesses about twice the cross-section of cotton, it becomes a

rather easy matter to calculate the ratio between the two, by means of which the percentage by weight can be readily obtained, provided that the specific gravity of wool is taken to be about the same as that of cotton, which is approximately true.

2. Analysis of Yarns in Cloth.—Dale (*Textile World*) gives the following scheme for the analysis of cloth for yarn count: A sample of the cloth having an area of $\frac{1}{300}$ sq. yd. (4.32 sq. ins.) is weighed in grains. This sample can be cut in any shape desired, but a rectangular form, 1.8 ins. by 2.4 ins., is the most convenient. For large patterns the weight of $\frac{1}{300}$ sq. yd. is calculated from the weight of a larger sample.

The grain weight of $\frac{1}{300}$ sq. yd. and the number of warp and filling threads per inch having been determined, the " straight line " calculations are made as follows:

1. Average cotton yarn number = threads per inch ÷ grains per $\frac{1}{300}$ sq. yd.

The cotton yarn number of any particular group of threads can be determined by the same method after counting and weighing separately.

2. Average cotton yarn number = (threads per inch × square yards per pound) ÷ $23\frac{1}{3}$.

3. Average cotton yarn number = (threads per inch × 24) ÷ (ounces per square yard × 35).

4. Ounces per running yard $52\frac{1}{2}$ ins. wide = grains per $\frac{1}{300}$ sq. yd., no calculation being necessary.

5. Ounces per running yard = (grains per $\frac{1}{300}$ sq. yd. × width in inches) ÷ $52\frac{1}{2}$.

6. Ounces per square yard = (grains per $\frac{1}{300}$ sq. yd. × 36) ÷ $52\frac{1}{2}$.

7. Ounces per square yard = (grains per $\frac{1}{300}$ sq. yd. × 300) ÷ $437\frac{1}{2}$.

8. Grains per square yard = 7000 ÷ square yards per pound.

9. Square yards per pound = 16 ÷ ounces per square yard.

10. Square yards per pound = 840 ÷ (36 × grains per $\frac{1}{300}$ sq. yd.).

11. Square yards per pound = 7000 ÷ (300 × grains per $\frac{1}{300}$ sq. yd.).

12. Running yards per pound = 840 ÷ (width in inches × grains per $\frac{1}{300}$ sq. yd.).

13. Woolen runs = cotton yarn number × $0.52\frac{1}{2}$.

14. Worsted yarn number = cotton yarn number × $1\frac{1}{2}$.

15. Linen lea or woolen cut = cotton yarn number × 2.8.

The spun yarn number is calculated for cotton, woolen, worsted and linen from the finished yarn number by allowing for changes that may have occurred in length and weight. In the following formulæ these changes are expressed by the yield of finished cloth in percentage. Thus, if the spun yarn shrinks 10 percent in length or weight in weaving and finishing, the yield of finished cloth is 90 percent.:

16. Spun yarn number = finished yarn number ÷ yield percent in length.

17. Spun yarn number = finished yarn number × yield percent in weight.

18. Spun yarn number = (finished yarn number × yield percent in weight) ÷ yield percent in length.

3. Determination of the Size of Yarns.—Yarns are classified as coarse or fine according to their relative thickness or weight per given length. This is known as the *size* or *count* of the yarn. There are a large number of different standards employed for determining the numbers of yarns depending on the character of the fiber (wool, silk, cotton, linen, etc.) and on the locality in which the yarns are spun. The English system for

numbering woolen, worsted, and cotton yarns is the most extensively employed throughout the world, while for the numbering of silk yarns the French system is used chiefly on the European continent.

The determination of the count of a yarn is based upon one of two methods: (*a*) the weight of a definite length of the yarn, in which case the weight of the standard length is designated as the yarn number; this method is principally employed in the case of silk; (*b*) the length of a definite weight of the yarn, in which case the numbers will depend on the system of weights adopted; the English system employing the English weights, and the metric system using the metric weights. This method is used for yarns of wool, cotton, spun silk, linen, etc.

In the English standards for various fibers, No. 1 yarn has the following yards per pound:

Cotton	840 yards
Linen	300 "
Woolen	1600 "
Worsted	560 "
Spun silk	840 "

The following table gives the equivalent counts of the different yarns for the same weight per yard:

Cotton (Hanks of 840 Yards).	Linen (Cuts of 300 Yards).	Woolen (Runs of 1600 Yards).	Worsted (Hanks of 560 Yards).	Thrown Silk (Yards in One Ounce).
1	2.8	0.525	1.5	52.5
0.357	1	0.187	0.54	18.7
1.9	5.3	1	2.85	100.0
0.66	1.85	0.346	1	34.6
0.019	0.053	0.01	0.029	1

The apparatus employed for determining the weight of the prescribed length of yarn may be an ordinary balance or scales, though special yarn balances are made with arcs variously graduated according to the system of counts desired, thus giving the size of the yarn as a direct reading.

It is to be regretted that there is not a uniform system for numbering yarns, for at the present time the matter is in a rather chaotic state, each fiber having its own special system, and these systems also varying widely in different localities. There have been many attempts recently made to introduce the metric system of numbering as being a convenient and logical one, but without any marked degree of success. It has also been proposed to adopt a simple English standard in which the unit of length would be 1000 yds. and the unit of weight 1 lb, then the count of the yarn would indicate the number of 1000-yd. units contained in

1 lb. by weight. Such a system would greatly simplify the present complicated methods of yarn counting. But owing to the fact that reels and testing apparatus have been made in conformity with the present standard sizes, and that the prices paid for the manufacture of yarns are based on specified numbers, any radical change in the systems of yarn numbering would entail a complete readjustment throughout the textile industry; consequently any attempt at sudden change of system is doomed to failure.

It has been found that tests on yarn for determining the count in the condition received vary somewhat according to the moisture in the sample and the humidity of the atmosphere at the time of testing. Thus it was found that for a sample of normal gray cotton yarn tested throughout a period of three months the moisture varied from 6 to 10 percent. Assuming the yarn to have been 40's, this corresponds to an apparent variation between 41's and 39's. With respect to the influence of humidity on strength tests on wool, cotton, and linen cloths, it was shown that the strength depends to a considerable extent upon the conditions of the atmosphere to which the cloth is exposed prior to testing. Pieces were cut into six strips in the direction of the warp and tested for strength in the same direction under various conditions as to variation in the relative humidity of the atmosphere and the average strength of the samples from the six strips was also taken. An ordinary gray cotton drill and a linen canvas showed an increase or decrease in strength according as there was an increase or a decrease in the relative humidity of the atmosphere; the difference in strength varying as much as 12 and 18 percent, respectively. A wool cloth serge showed a decrease or increase in strength with increase or decrease in the relative humidity of the atmosphere, the results in this case varying as much as 14 percent. The necessity of adopting some uniform conditions of humidity and probably also of temperature under which the test should be carried out is thus emphasised, and materials should not be rejected as not being in agreement with the specifications unless reliable tests have been made under conditions of humidity and temperature which are stated and agreed upon in the specifications to which the sample of cloth is supposed to apply.

The general principle underlying the determination of the yarn number is to reel off the yarn in hanks of a definite number of yards (English system) or meters (Metric system), and then determine the weight of these hanks; the number of such hanks required to give the standard weight determines the count of the yarn.

The number of yards of the various yarns that weigh the following amount in grains, is the English count of that yarn:

Cotton yarn	8.330	grains
Woolen yarn	4.375	"
Worsted yarn	12.500	"
Linen yarn	23.330	"

4. Size of Cotton Yarns.—The number or count [1] of cotton yarn is determined by the number of hanks of 840 yds. each contained in 1 lb. This is the basis of the English system and is in use throughout England, America, Germany, India, and Switzerland. The French method of numbering is based on the decimal system, and the count means the number of hanks each 1000 meters in length required to weigh 500 grams. To pass from the French (metric) system into the English, and conversely, use the following factors:

$$\text{English count} = \text{French count} \times 1.18.$$

$$\text{French count} = \text{English count} \times 0.847.$$

The Belgian method of counting is to use the number of 840-yd. hanks in 500 grams. The Austrian system is the number of hanks of 950 ells each contained in 500 grams. Doubled or twisted yarns are designated in the same manner as single yarns, except that the number of threads is also given, for instance, if two single threads of count 20 are twisted together, the yarn is described as 2–20's or $\frac{2}{20}$ or 20/2; a three-ply yarn would be 3–20's or $\frac{3}{20}$ or 2 30, etc. According to the number of threads twisted together, yarns will lose from 2.5 to 6 percent of their length in doubling, and, of course, become correspondingly thicker. Yarns containing more than two single threads are known as sewing twist or cord.

In order to avoid the necessity of reeling off such a large quantity as 840 yds., the hank is divided into 7 *leas* of 120 yds. each. The standard reel employed has a circumference of $1\frac{1}{2}$ yds. (54 ins.), hence a lea (or lay) is equivalent to 80 turns of the reel. We have the following relations:

$$1 \text{ thread} = 1\tfrac{1}{2} \text{ yds.}$$
$$80 \text{ threads} = 1 \text{ lea} = 120 \text{ yds.}$$
$$7 \text{ leas} = 1 \text{ hank} = 840 \text{ yds.}$$

COMPARATIVE TABLE OF FRENCH AND ENGLISH YARN NUMBERS

French.	English.	French.	English.	French.	English.	French.	English.
1	1.18	11	12.1	21	24.8	32	37.8
2	2.23	12	14.2	22	26.0	34	40.1
3	3.54	13	15.3	23	27.2	36	42.5
4	4.72	14	16.5	24	28.3	38	44.8
5	5.90	15	17.7	25	29.5	40	47.2
6	7.80	16	18.9	26	30.7	45	52.1
7	8.26	17	20.1	27	31.8	50	59.0
8	9.44	18	21.2	28	33.0	55	64.9
9	10.62	19	22.4	29	34.2	60	70.8
10	11.80	20	23.6	30	35.4		

[1] In England the count of yarn is frequently called the "grist."

The finest number of cotton yarn to be met with in commerce is 240; numbers higher than this have rarely been spun in any amounts. Up to 20's the counts rise by single numbers, such as 1, 2, 3, 4, 5, etc. Beyond 20's it is customary to make use of only the even numbers, like 22, 26, 30, etc. Above 60's the numbers rise by 5, such as 65, 70, 75, etc., and above 100's they rise by 10. The coarsest yarns used for weaving are 6's and 8's; though yarns of coarser count than these are employed for lamp-wicks, cordage, etc.

The following variations above and below the exact standard representing the counts of various yarns are allowed:

	Percent.
1. Cotton yarns Nos. 1 to 10, English	2.5
Waste yarn, including so-called "imitation" yarns, up to No. 6	4.0
Cotton yarns Nos. 11 to 20	2.0
" Nos. 21 to 40	2.5
" above No. 40	3.0
2. Worsted yarn	1.5
3. Carded yarn	2.5
Shoddy from wool	4.0
4. Mixed wool and cotton yarn	2.5
" " silk	1.5
5. Linen yarn	2.5
6. Jute yarn	3.0

The following table shows the comparative length of different counts of cotton yarn:

No.	Yards per Pound.	Weight per 1000 Yards, Ounces.	No.	Yards per Pound.	Weight per 1000 Yards, Ounces.	No.	Yards per Pound.	Weight per 1000 Yards, Ounces.
4	3,360	4.76	16	13,440	1.19	36	30,240	0.517
6	5,040	3.18	18	15,120	1.065	40	33,600	0.476
8	6,720	2.38	20	16,800	0.952	44	36,960	0.433
10	8,400	1.90	24	20,160	0.795	50	42,000	0.380
12	10,080	1.59	28	23,520	0.695	60	50,440	0.317
14	11,760	1.39	32	26,880	0.595	80	67,200	0.238

The following table gives the counts of cotton yarns by the weight in grains of 1 skein of 120 yds.:

120 Yards Weigh, Grains.	Count of Yarn.	120 Yards Weigh, Grains.	Count of Yarn.	120 Yards Weigh, Grains.	Count of Yarn.	120 Yards Weigh, Grains.	Count of Yarn.
1	1000	15	67	27	37	50	20
2	500	15.5	65	27.5	36.5	52	19
3	333	16	63	28	36	54	18.5
4	250	16.5	61	28.5	35	56	18
5	200	17	59	29	34.5	58	17
5.5	181	17.5	57	29.5	34	62	16
6	167	18	56	30	33.5	66	15
6.5	154	18.5	54	30.5	33	70	14
7	143	19	53	31	32.5	74	13.5
7.5	133	19.5	51	31.5	32	78	13
8	125	20	50	32	31	83	12
8.5	118	20.5	49	33	30	91	11
9	111	21	48	34	29.5	100	10
9.5	105	21.5	47	35	29	111	9
10	100	22	45	36	28	125	8
10.5	95	22.5	44	37	27	143	7
11	91	23	43	38	26	167	6
11.5	87	23.5	42.5	39	25.5	200	5
12	83	24	42	40	25	250	4
12.5	80	24.5	41	41	24.5	334	3
13	77	25	40	42	24	500	2
13.5	74	25.5	39	44	23	1000	1
14	71	26	38	46	22		
14.5	69	26.5	37.5	48	21		

A short method of determining the count of cotton yarn when only a short length is available is to weigh off in grains 12 yds. of the yarn, and divide this number into 100. Thus, if 12 yds. weigh 5 grains, the count is $100 \div 5 = 20$.

To obtain the *yards per ounce* of any cotton yarn multiply the yarn count by the factor $52\frac{1}{2}$; for instance: 30's cotton yarn is equivalent to $30 \times 52\frac{1}{2} = 1575$ yds. per ounce. The calculation can be shortened by adding 5 percent more to one-half the yarn count and multiplying by 100; for example: 30's count equals $15 + 0.75 = 15.75 \times 100 = 1575$ yds. per ounce.

5. Woolen Yarns.—The English system numbering of woolen yarns is based on the number of "runs" in 1 lb.; a "run" is 1600 yds. As this is equivalent to 100-yd. lengths to 1 oz., the run system is very convenient for calculating the weight of yarns in ounces; thus, $1\frac{1}{4}$ runs is equivalent to 125 yds. per ounce. The following table gives the "runs" or count of woolen yarns by the weight in grains of 20 yds.:

20 Yards Weigh, Grains.	Runs.	20 Yards Weigh, Grains.	Runs.	20 Yards Weigh, Grains.	Runs.	20 Yards Weigh, Grains.	Runs.	20 Yards Weigh, Grains.	Runs.
1	87.5	21	4.2	41	2.13	61	1.43	81	1.08
2	43.7	22	4.0	42	2.08	62	1.41	82	1.07
3	29.2	23	3.8	43	2.03	63	1.38	83	1.05
4	21.9	24	3.6	44	1.99	64	1.37	84	1.04
5	17.5	25	3.5	45	1.94	65	1.35	85	1.03
6	14.6	26	3.4	46	1.90	66	1.33	86	1.02
7	12.5	27	3.2	47	1.86	67	1.31	87	1.01
8	10.9	28	3.1	48	1.82	68	1.29	88	0.99
9	9.7	29	3.0	49	1.79	69	1.27	89	0.98
10	8.7	30	2.9	50	1.75	70	1.25	90	0.97
11	7.9	31	2.8	51	1.72	71	1.23	91	0.96
12	7.3	32	2.7	52	1.68	72	1.22	92	0.95
13	6.7	33	2.6	53	1.65	73	1.20	93	0.94
14	6.2	34	2.6	54	1.62	74	1.18	94	0.93
15	5.8	35	2.5	55	1.59	75	1.17	95	0.92
16	5.5	36	2.4	56	1.56	76	1.15	96	0.91
17	5.2	37	2.36	57	1.54	77	1.14	97	0.90
18	4.9	38	2.30	58	1.51	78	1.12	98	0.89
19	4.6	39	2.24	59	1.48	79	1.11	99	0.88
20	4.4	40	2.19	60	1.46	80	1.09	100	0.87

In the metric or international system the count of woolen yarn is the number of hanks of 1000 meters weighing 1 kilogram.

In the American system the "cut" is frequently used for the count of woolen yarns. This is based on the number of cuts of 300 yds. in 1 lb. In the grain system the count is designated by the weight in grains of 20 yds.

6. Worsted Yarns.—The numbering of worsted yarns by the English system is based on the number of "hanks" of 560 yds. in 1 lb. The following table gives the count of worsted yarns by the weight in grains of 20 yds.:

20 Yards Weigh, Grains.	No. of Yarn.	20 Yards Weigh, Grains.	No. of Yarn.	20 Yards Weigh, Grains.	No. of Yarn.	20 Yards Weigh, Grains.	No. of Yarn.	20 Yards Weigh, Grains.	No. of Yarn.
1	250	23	10.87	45	5.56	67	3.73	89	2.81
2	125	24	10.42	46	5.43	68	3.68	90	2.78
3	83.33	25	10	47	5.32	69	3.62	91	2.75
4	62.50	26	9.62	48	5.21	70	3.57	92	2.72
5	50	27	9.26	49	5.10	71	3.52	93	2.69
6	41.67	28	8.93	50	5.00	72	3.47	94	2.66
7	35.71	29	8.62	51	4.90	73	3.42	95	2.63
8	31.25	30	8.33	52	4.81	74	3.38	96	2.60
9	27.78	31	8.06	53	4.72	75	3.33	97	2.58
10	25	32	7.81	54	4.63	76	3.29	98	2.55
11	22.73	33	7.58	55	4.55	77	3.25	99	2.52
12	20.83	34	7.35	56	4.46	78	3.21	100	2.50
13	19.23	35	7.14	57	4.39	79	3.17	105	2.38
14	17.86	36	6.94	58	4.31	80	3.12	110	2.27
15	16.67	37	6.76	59	4.24	81	3.09	115	2.17
16	15.62	38	6.58	60	4.17	82	3.05	120	2.08
17	14.71	39	6.41	61	4.10	83	3.01	125	2.00
18	13.89	40	6.25	62	4.03	84	2.98	150	1.67
19	13.16	41	6.10	63	3.97	85	2.94	175	1.43
20	12.50	42	5.95	64	3.91	86	2.91	200	1.25
21	11.90	43	5.81	65	3.85	87	2.87		
22	11.36	44	5.68	66	3.79	88	2.84		

The count of worsted yarns, where only short lengths are available, may be determined by dividing 150 by the weight in grains of 12 yds.; hence if 12 yds. weigh 5 grains, the count would be $150 \div 5 = 30$. Also this formula may be used:

$$\text{Count} = \frac{\text{yards weighed}}{0.08 \text{ weight in grains}}.$$

Five different systems are used in France for numbering worsted yarn:

	Yards per Pound.
Roubaix, old	708
Roubaix, new	354
Fourmies	352
Reims	347
Metric	496

The first four of these are used in the mills of France, while the fifth is the metric system, by which French yarn is usually numbered when offered for sale to foreign buyers. To reduce the metric number to the worsted count based on 560 yds. per pound: Multiply the metric number by 0.886. To reduce the worsted number (560 yds. per pound) to the metric count: Multiply the worsted number (560 yds. per pound) by 1.129.

7. Silk Yarns.—The fineness or size of raw silk thread is expressed by a number known as *titre* (in French) or *titolo* (in Italian); this gives the number of units of certain weight (denier = 53.13 mgms.) a skein of certain length will weigh. Several different standards are in use in Europe at the present time, among which are the following:

	Weight in Grams.	Length in Meters.
Denier (Italian, *legal*)	0.05	450
Denier (*Milan*)	0.051	476
Denier (*Turin*)	0.0534	476
Old denier (*Lyons*)	0.0531	476
New denier (*Lyons*)	0.0531	500
Denier (international)	0.05	500

The titre is usually expressed in the form of a fraction, representing limits of variation, as all skeins are not of absolutely the same size. A silk marked $\frac{18}{20}$, for instance, would mean that it varied from 18 to 20 deniers.

The denier is supposed to be derived from the weight of a Roman coin of small value called *denarius*. The abbreviation for pence (*d*) in the English monetary system is derived also from this word. The origin and history of the denier are quite interesting. The denier was a small coin, originally of silver, and was introduced into Gaul by the Romans, probably about the time of Cæsar's Gallic wars. The value of this piece was about 16 cents. Later, the name denier was applied to both gold and copper coins as well. It is claimed that it was the latter which was originally used as a weight, but this is uncertain. However, the denier, whichever it was, weighed 24 grains Poids de Marc. The old method of grading silk was to take 80 skeins of 120 aunes (giving a total length of 9600 aunes) and find their weight in deniers. Toward the end of the eighteenth century, one Matley, observing that the grain was $\frac{1}{24}$ of the denier, conceived the idea of taking skeins of 400 aunes (or $\frac{1}{24}$ of 9600) and weighing these in grains, thus preserving the ratio. He made a machine for measuring these skeins of 400 aunes. The trade accepted

the change, but could not get rid of the old term denier, which now became fastened to the new grain weight, so that the denier weight as we know it to-day, is really a 1-grain Poid de Marc, and $\frac{1}{24}$ of its original value. The present denier has a value of 0.0531 gram = 0.833 grain, and the 400 aunes skein is equal to 476 meters = 520 yds. and 20 ins.

The international denier (adopted by the International Yarn Numbering Congress, held in Vienna in 1873) may, perhaps, be more conveniently defined as being the weight (in grams) of 10,000 meters. The basis for the sizing of thrown silk in England and the United States is the weight in *drams* of 1000 yds. To convert this weight into deniers, it is necessary to multiply by the factor 33.36. For example, if 1000 yds. of silk weigh 3 drams, it would be equivalent to $33.36 \times 3 = 100.08$ deniers. In France the size of the silk is usually expressed in terms of the old denier, which was the weight in deniers of 400 French ells. The latter length is equivalent to 476 meters, and the denier is equal to 0.05313 gram. Hence, to obtain the size in deniers according to this system, multiply the weight in grams of 476 meters by the factor 18.82 ($= 1 \div 0.05313$). For example, if 476 meters of silk weigh 5 grams, this would be equivalent to $5 \times 18.82 = 94.1$ deniers. To obtain the deniers under the new measure, the weight in grams of 500 meters is multiplied by the factor 18.82. The *legal measure* in France of the size of silk is represented by the weight in grams of 500 meters, but it is probably more usual to express the size in terms of deniers. To convert the new denier into the old denier, multiply by the factor $0.952\left(=\frac{476}{500}\right)$. The denier on the *old system* may be converted into the *international measure* (based on a weight of 0.05 gram for a length of 500 meters) by multiplying by the factor 1.116; and, inversely, the international denier may be converted into the old system denier by multiplying by the factor 0.896.

To determine the length per pound of a given size of silk divide 4,465,000 yds. by the number of deniers and the result will be yards per pound.

In the numbering of silk yarns the denier system is used for raw silk and the dram system is used for thrown silk in the United States. A 1-denier silk would measure 4,464,528 yds. per pound, and a $\frac{14}{16}$-denier (average 15) would measure $\frac{1}{15}$ of this, and so on. A 1-dram silk measure 256,000 yds. per pound, and a 2-dram silk would be $\frac{1}{2}$ of this, and so on. Consequently to reduce deniers to drams divide the deniers by the factor 17.44.

The following tables show the relations between the different measures of the French scale:

Legal Titer.	New Denier.	Old Denier.	Internat. Denier.	Legal Titer.	New Denier.	Old Denier.	Internat. Denier.
Weight of 500 Meters in Grams.	Weight of 500 Meters in Deniers.	Weight of 476 Meters in Deniers.	Weight of 10,000 Meters in Grams.	Weight of 500 Meters in Grams.	Weight of 500 Meters in Deniers.	Weight of 476 Meters in Deniers.	Weight of 10,000 Meters in Grams.
0.1	1.88	1.78	2	4.1	77.16	73.45	82
0.2	3.76	3.58	4	4.2	79.05	75.25	84
0.3	5.64	5.36	6	4.3	80.93	77.04	86
0.4	7.52	7.16	8	4.4	82.81	78.83	88
0.5	9.41	8.95	10	4.5	84.69	80.62	90
0.6	11.29	10.73	12	4.6	86.58	82.42	92
0.7	13.17	12.53	14	4.7	88.46	84.21	94
0.8	15.05	14.32	16	4.8	90.34	86.00	96
0.9	16.93	16.11	18	4.9	92.22	87.79	98
1.0	18.82	17.91	20	5.0	94.10	89.58	100
1.1	20.70	19.70	22	5.1	95.99	91.38	102
1.2	22.58	21.49	24	5.2	97.87	93.17	104
1.3	24.46	23.28	26	5.3	99.75	94.96	106
1.4	26.35	25.08	28	5.4	101.63	96.75	108
1.5	28.23	27.87	30	5.5	103.51	98.54	110
1.6	30.11	28.66	32	5.6	105.40	100.33	112
1.7	31.99	30.45	34	5.7	107.28	102.12	114
1.8	33.87	32.24	36	5.8	109.16	103.92	116
1.9	35.76	34.04	38	5.9	111.04	105.71	118
2.0	37.64	35.83	40	6.0	112.93	107.50	120
2.1	39.52	37.62	42	6.1	114.81	109.29	122
2.2	41.40	39.41	44	6.2	116.69	111.08	124
2.3	43.29	41.20	46	6.3	118.57	112.87	126
2.4	45.17	43.00	48	6.4	120.45	114.66	128
2.5	47.05	44.78	50	6.5	122.34	116.46	130
2.6	48.93	46.57	52	6.6	124.22	118.25	132
2.7	50.81	48.57	54	6.7	126.10	120.04	134
2.8	52.70	50.16	56	6.8	127.98	121.83	136
2.9	54.58	51.95	58	6.9	129.87	123.63	138
3.0	56.46	53.74	60	7.0	131.75	125.42	140
3.1	58.34	55.54	62	7.1	133.63	127.21	142
3.2	60.22	57.33	64	7.2	135.51	129.00	144
3.3	62.11	59.12	66	7.3	137.39	130.80	146
3.4	63.99	60.91	68	7.4	139.28	132.59	148
3.5	65.87	62.70	70	7.5	141.16	134.39	150
3.6	67.75	64.49	72	7.6	143.04	136.17	152
3.7	69.64	66.29	74	7.7	144.92	137.96	154
3.8	71.52	68.08	76	7.8	146.80	139.70	156
3.9	73.40	69.87	78	7.9	148.69	141.56	158
4.0	75.28	71.66	80	8.0	150.57	143.34	160

Legal Titer.	New Denier.	Old Denier.	Internat. Denier.	Legal Titer.	New Denier.	Old Denier.	Internat. Denier.
Weight of 500 Meters in Grams.	Weight of 500 Meters in Deniers.	Weight of 476 Meters in Deniers.	Weight of 10,000 Meters in Grams.	Weight of 500 Meters in Grams.	Weight of 500 Meters in Deniers.	Weight of 476 Meters in Deniers.	Weight of 10,000 Meters in Grams.
8.1	152.45	145.13	162	10.1	190.09	180.97	202
8.2	154.33	146.92	164	10.2	191.98	182.76	204
8.3	156.22	148.71	166	10.3	193.86	184.55	206
8.4	158.10	150.50	168	10.4	195.74	186.35	208
8.5	159.98	152.30	170	10.5	197.62	188.14	210
8.6	161.86	154.08	172	10.6	199.51	189.93	212
8.7	163.74	155.88	174	10.7	201.39	191.72	214
8.8	165.63	157.67	176	10.8	203.27	193.51	216
8.9	167.51	159.46	178	10.9	205.15	195.30	218
9.0	169.39	161.25	180	11.0	207.03	197.10	220
9.1	171.27	163.04	182	11.1	208.92	198.09	222
9.2	173.16	164.84	184	11.2	210.80	200.68	224
9.3	175.04	166.63	186	11.3	212.68	202.47	226
9.4	176.92	168.42	188	11.4	214.56	204.26	228
9.5	178.80	170.21	190	11.5	216.45	206.06	230
9.6	180.68	172.00	192	11.6	218.33	207.85	232
9.7	182.57	173.80	194	11.7	220.21	209.64	234
9.8	184.45	175.59	196	11.8	222.09	211.43	236
9.9	186.33	177.38	198	11.9	223.97	213.22	238
10.0	188.21	179.17	200	12.0	225.86	215.01	240

Dorgin (*American Silk Journal*) gives the following tables for Japan silk, Tsatlee silk, and Tussah silk yarns:

Japan Silk Yarn

This table is based on the customary 13/15 denier raw silk, or the 15 denier full thrown silk; the allowance for loss in boil-off is 25 percent.

Thread.	Japan Tram in Gum		Japan Tram in Boil-off.	
	Denier.	Yards per Pound.	Denier.	Yards per Pound.
2	30	148,818	22.50	198,423
3	45	99,212	33.75	132,282
4	60	74,409	45.00	99,212
5	75	59,527	56.25	79,369
6	90	49,606	67.50	66,141
7	105	42,512	78.75	56,922
8	120	37,204	90.00	49,606
9	135	33,071	101.25	44,094
10	150	29,764	112.50	39,685
11	165	27,058	123.75	36,077
12	180	24,803	135.00	33,071
13	195	22,895	146.25	30,217
14	210	21,260	157.50	28,346
15	225	19,842	168.75	26,456

Tsatlee Silk Yarn

This table is based on single 25's denier full thrown silk; the allowance for boil-off is 25 percent.

Thread.	Tsatlee Tram in Gum.		Tsatlee Tram in Boil-off.	
	Denier.	Yards per Pound.	Denier.	Yards per Pound.
2	50	89,291	37.50	119,054
3	75	59,527	56.25	79,369
4	100	44,645	75.00	59,527
5	125	35,716	93.75	47,622
6	150	29,764	112.50	39,685
7	175	25,512	131.25	34,015
8	200	22,323	150.00	29,764
9	225	19,842	168.75	26,456
10	250	17,858	187.50	23,811

Tussah Silk Yarn

This table is based on 8-cocoon single 40 denier full thrown silk; the allowance for boil-off is 25 percent.

Thread.	Tussah Tram in Gum		Tussah Tram in Boil-off.	
	Denier.	Yards per Pound.	Denier.	Yards per Pound.
2	80	55,807	60	74,409
3	120	37,204	90	49,606
4	160	27,903	120	37,204
5	200	22,323	150	29,764
6	240	18,602	180	24,803
7	280	15,045	210	21,260
8	320	13,952	240	18,602
9	360	12,401	270	16,535
10	400	11,161	300	14,882

The following table shows the comparison between drams, grams, and deniers:

Drams.	Grams.	Deniers	Drams.	Grams.	Deniers.
0.0299	0.05313	1.0	2.50	4.43	83.4
0.25	0.44	8.3	2.75	4.87	91.6
0.50	0.88	16.5	3.00	5.31	100.0
0.568	1.00	18.82	4.00	7.09	133.0
0.75	1.33	25.0	5.00	8.86	166.0
1.00	1.771875	33.36	6.00	10.63	199.0
1.25	2.21	41.6	7.00	12.40	233.0
1.50	2.65	50.0	8.00	14.17	265.0
1.75	3.10	58.3	9.00	15.95	299.0
2.00	3.54	66.6	10.00	17.72	333.0
2.25	3.98	75.0			

To convert the new international titer into any of the older standards multiply by the following factors:

To Turin titer	×0.8931
To Milan titer	×0.9315
To French titer	×0.8964
To Italian (legal) and Swiss titer	×0.9000

Conversely, to convert any of the above old titers into the new international equivalent, divide by the above factors.

Conversion factors in silk numbering:

2776 ÷ deniers	= runs
5289 ÷ deniers	= cotton number
7932 ÷ deniers	= worsted number
160 ÷ drams	= runs
305 ÷ drams	= cotton number
457 ÷ deniers	= worsted number
2776 ÷ runs	= deniers
5289 ÷ cotton number	= denier
7932 ÷ worsted number	= denier
160 ÷ runs	= drams
305 ÷ cotton number	= drams
457 ÷ worsted number	= drams
deniers × 0.0576	= drams
drams × 17.352	= deniers

For the sizing of **spun silk** the unit of the English scale is a hank of 840 yds., and the number of such hanks in 1 lb. is the count of the yarn. There is a difference in the counting of doubled spun silk from that of doubled cotton yarn, in that with cotton " 2–40's " means single 40's doubled to 20's; whereas, with spun silk " 2–40's " means single 80's doubled to 40's, and " 3–40's " would mean single 120's tripled to 40's, etc.

In France and Switzerland the number or size of spun silk indicates the number of skeins of 1000 meters in 1 kilogram. To convert the English number into the French or metric number multiply by the factor 1.69; and to convert the French number into the English number multiply by the factor 0.59.

Dorgin [1] gives the following table for the sizing of spun silk yarns:

SPUN SILK YARNS

Count.	2- or More-Ply, Yds. to Lb. in Gray.	Count.	2- or More-Ply, Yds. to Lb. in Gray.
2	1,680	24	20,160
3	2,520	26	21,840
4	3,360	28	23,520
6	5,040	30	25,200
8	6,720	32	26,880
9	7,560	34	28,560
10	8,400	36	30,240
12	10,080	40	33,600
14	11,760	42	35,280
15	12,600	48	40,320
16	13,440	54	45,360
18	15,120	60	50,400
20	16,800	72	60,480
21	17,640	75	63,000
22	18,480	80	67,200

[1] *American Silk Journal.*

On colored spun silks an allowance of about 5 percent on the above measurements should be made for contraction in length of the silk in the processes of dyeing.

Sewing silk is numbered irregularly by letters, OOO, OO, O, A, B, C, D, E, EE, F, FF, G. The yards in one ounce for the respective letters are 2000, 1600, 1300, 1000, 850, 650, 550, 400, 330, 262, 212, and 125.

Thrown silk in Europe is graded in the same manner as raw silk, but with American and English throwsters the adopted custom of specifying the counts of raw silk yarns is to give the weight of a hank of 1000 yds. in drams avoirdupois; thus, if such a hank weighs 5 drams, it is technically known as 5-dram silk. The size of yarn is always given for the "gum weight"; that is, its condition before boiling-off. In this latter process yarns lose from 15 to 30 percent, according to the class of raw silk used, Chinese silks losing the most and Japanese and European silks the least. The following table shows the number of yards to the pound and ounce of silk of different dram sizes. The number of yards per pound being based on a pound of gum silk:

LENGTH OF GUM SILK YARN PER POUND AND PER OUNCE

Drams per 1000 Yards.	Yards per Pound.	Yards per Ounce.	Drams per 1000 Yards.	Yards per Pound.	Yards per Ounce.
1	256,000	16,000	9	28,444	1778
1¼	204,800	12,800	9½	26,947	1684
1½	170,666	10,667	10	25,600	1600
1¾	146,286	9,143	11	23,273	1455
2	128,000	8,000	12	21,333	1333
2¼	113,777	7,111	13	19,692	1231
2½	102,400	6,400	14	18,286	1143
2¾	93,091	5,818	15	17,067	1067
3	85,333	5,333	16	16,000	1000
3¼	78,769	4,923	17	15,058	941
3½	73,143	4,571	18	14,222	889
3¾	68,267	4,267	19	13,474	842
4	64,000	4,000	20	12,800	800
4¼	60,235	3,765	21	12,190	762
4½	56,889	3,556	22	11,636	727
4¾	53,368	3,368	23	11,130	696
5	51,200	3,200	24	10,667	666
5½	46,545	2,909	25	10,240	640
6	42,667	2,667	26	9,846	615
6½	39,385	2,462	27	9,481	592
7	36,571	2,286	28	9,143	571
7½	34,133	2,133	29	8,827	551
8	32,000	2,000	30	8,533	533
8½	30,118	1,882			

Another method of sizing silk yarns which is sometimes used is the *ounce system*. This system is mostly used in connection with other trades than weaving and knitting, and where thick counts of yarn are employed: The system is based on the weight in ounces of a 1000-yd. hank. We thus have three methods of sizing thrown silk:

1. Denier system. 2. Dram system. 3. Ounce system.

To ascertain the equivalent count of a given yarn in any of these systems, proceed as follows:

(*a*) Denier to dram $\times 0.058$.
(*b*) Denier to ounce $\times 0.0036$.
(*c*) Dram to denier $\times 17\frac{1}{3}$.
(*d*) Dram to ounce $\times 0.0625$.
(*e*) Ounce to denier $\times 277\frac{1}{3}$.
(*f*) Ounce to dram $\times 16$.

To convert the count of raw silk into the equivalent for spun silk:

(*a*) Denier system into spun silk count $-5282 \div$ deniers $=$ spun silk count, and $5282 \div$ spun silk count $=$ deniers.

(*b*) Dram system into spun silk count $-304.7 \div$ drams $=$ spun silk count, and $304.7 \div$ spun silk count $=$ drams.

(*c*) Ounce system into spun silk count $-19.4 \div$ ounces $=$ spun silk count, and $19.4 \div$ spun silk count $=$ ounces.

The average limits within which the sizes of various grades of silks fluctuate are:

Raw silk	9 to 30 deniers
Organzine	18 to 34 "
Tram	24 to 60 "
Wild silk	100 to 300 "

During the process of reeling the cocoon filaments, the latter may, for one reason or another, run out previous to starting another cocoon; or to make up for the cocoons left out during the reeling, the operator may add extra cocoons. From such conditions it will easily be understood that it is practically impossible to produce a thread of absolute uniformity throughout the entire skein. Owing to this variation in the size of silk, in order to obtain accurately the size of any lot of silk under consideration, it is necessary to take the average of several tests from different parts of the bale. These irregularities in silk make it necessary in commercial transactions to permit a variation of two deniers in any lot of silk.

The following table shows the sizes of silk yarns in deniers as compared with the sizes of cotton yarns (English system):

COMPARATIVE TABLE OF COUNTS OF COTTON AND SILK YARNS OF EQUIVALENT SIZE

Cotton.			Silk.	
Single.	Double.	Yards per Pound.	Drams.	Deniers.
16–1	32–2	13,440	17.04	296.83
18–1	36–2	15,120	16.89	294.22
20–1	40–2	16,800	15.24	265.48
22–1	44–2	18,480	13.86	241.44
24–1	48–2	20,160	12.69	221.00
26–1	52–2	21,840	11.72	204.16
28–1	56–2	23,520	10.88	189.52
30–1	60–2	25,200	10.20	177.68
32–1	64–2	26,880	9.52	165.83
34–1	68–2	28,560	8.96	156.08
36–1	72–2	30,240	8.46	147.37
38–1	76–2	31,920	8.02	139.70
40–1	80–2	33,600	7.62	132.75
42–1	84–2	35,280	7.26	126.46
44–1	88–2	36,960	6.92	120.54
46–1	92–2	38,640	6.62	115.32
48–1	96–2	40,320	6.34	110.44
50–1	100–2	42,000	6.08	105.91
52–1	104–2	43,680	5.86	102.08
54–1	108–2	45,360	5.64	98.24
56–1	112–2	47,040	5.44	94.76
58–1	116–2	48,720	5.25	91.45
60–1	120–2	50,400	5.08	88.48
62–1	124–2	52,080	4.92	85.90
64–1	128–2	53,760	4.76	82.91
66–1	132–2	55,440	4.62	80.48
68–1	136–2	57,120	4.48	78.04
70–1	140–2	58,800	4.35	75.77
72–1	144–2	60,480	4.23	73.68
74–1	148–2	62,160	4.12	71.77
76–1	152–2	63,840	4.01	69.85
78–1	156–2	65,520	3.91	68.11
80–1	160–2	67,200	3.81	66.37
82–1	164–2	68,880	3.72	64.80
84–1	168–2	70,560	3.63	63.23
86–1	172–2	72,240	3.55	61.84
88–1	176–2	73,920	3.46	60.27
90–1	180–2	75,600	3.39	58.95
92–1	184–2	77,280	3.31	57.65
94–1	188–2	78,960	3.24	56.44
96–1	192–2	80,640	3.18	55.39
98–1	196–2	82,320	3.11	54.17
100–1	200–2	84,000	3.05	53.13
102–1	204–2	85,680	2.90	52.08
104–1	208–2	87,360	2.93	51.04
106–1	212–2	89,040	2.88	50.16
108–1	216–2	90,720	2.82	49.12
110–1	220–2	92,400	2.77	48.25
112–1	224–2	94,080	2.72	47.48
114–1	228–2	95,760	2.67	46.51
116–1	232–2	97,440	2.63	45.81
118–1	236–2	99,120	2.58	44.94
120–1	240–2	100,800	2.54	44.24

8. Artificial Silk Yarns.—The size or count of artificial silk is expressed in deniers corresponding to the number of grams in a length of 9000 meters. This is very close to the Lyons denier.

Dorgin [1] gives the following table for the counts of artificial silk:

ARTIFICIAL SILK

Denier.	Yards per Pound.	Denier.	Yards per Pound.	Denier.	Yards per Pound.	Denier.	Yards per Pound.
50	89,201	150	29,764	250	17,858	350	12,756
60	74,409	160	27,903	260	17,171	360	12,401
70	63,779	170	26,262	270	16,535	370	12,066
80	55,807	180	24,803	280	15,945	380	11,749
90	49,606	190	23,497	290	15,395	390	11,447
100	44,645	200	22,323	300	14,882	400	11,161
110	40,587	210	21,260	310	14,402	450	9,921
120	37,204	220	20,293	320	13,952	500	8,929
130	34,342	230	19,411	330	13,529	550	8,118
140	31,889	240	18,602	340	13,131	600	7,441

Artificial silk involves the question of specific gravity which cannot be compared with the specific gravity of real silk; artificial silk, as well known, will cover less for a given unit than real silk, for which reason allowance must be made for this property.

The following table gives the corresponding counts of yarns of similar size (yards per pound) of artificial silk, thrown silk, cotton and spun silk:

Cotton 2-ply, 3-ply, and 4-ply has $\frac{1}{2}$, $\frac{1}{3}$, and $\frac{1}{4}$ the number of hanks and yardage per pound its counts and numbers indicate. For instance, 1/10 = 4200 yds. to the pound, 3/10 = 2800 yds.

Spun silk in 2-ply, 3-ply, etc., has the number of hanks per pound and yardage its count indicates. For instance, 10/1 = 8400 yds. to pound, 10/2 the same, etc.

Thrown silk loses in dyeing, in average 25 percent, hence 1 lb. or 16 ozs. gray will give 12 ozs. dyed, pure dye, making it necessary to add $33\frac{1}{3}$ percent to the gum or gray yards per pound to obtain the dyed yardage per pound of 16 ounces: thus, 46 drams 5565 yds. per gum pound, plus $33\frac{1}{3}$ percent = 1855 = 7420 yds. per dyed pound.

[1] *American Silk Journal*

Artificial Silk.		Thrown Silk.			Cotton and Spun Silk Singles, 840 Yards per Hank.	
Deniers.	Yards per Pound.	Drams.	Yards per Pound in Gum.	Yards per Pound in Boil-off.	No.	Yards per Pound.
60	74,409	4½	56,889	75,852	90	75,600
70	63,779	5⅜	47,628	63,504	76	63,840
80	55,806	6⅛	41,796	55,728	66	55,440
90	49,606	6⅞	37,236	49,648	60	50,400
100	44,645	7⅝	33,572	44,762	54	45,360
110	40,587	8⅜	30,568	40,757	48	40,320
120	37,204	9⅛	28,055	37,407	46	38,640
130	34,342	9⅞	25,924	34,565	41	34,440
140	31,890	10¾	23,814	31,752	38	31,920
150	29,764	11½	22,260	29,680	35	29,400
160	27,903	12¼	20,898	27,864	33	27,720
170	26,662	13	19,692	26,256	31	26,040
180	24,803	13¾	18,618	24,824	29	24,360
190	23,497	14½	17,655	23,540	28	23,520
200	22,323	15¼	16,786	22,381	27	22,680
210	21,260	16	16,000	21,333	26	21,840
220	20,293	16¾	15,284	20,378	24	20,160
230	19,411	17½	14,628	19,504	23	19,320
240	18,602	18¼	14,028	18,704	22	18,480
250	17,858	19	13,474	17,965	21	17,640
260	17,171	20	12,800	17,067	20	16,800
270	16,535	20¾	12,337	16,449		
280	15,945	21½	11,907	15,876	19	15,960
290	15,395	22	11,636	15,515	18	15,120
300	14,882	23	11,130	14,840		
310	14,401	23½	10,894	14,525	17	14,280
320	13,951	24½	10,449	13,932	16	13,440
330	13,529	25	10,240	13,653		
340	13,131	26	9,846	13,128		
350	12,756	26½	9,663	12,883	15	12,600
360	12,401	27½	9,309	12,412		
370	12,066	28½	8,983	11,977		
380	11,749	29	8,827	11,769	14	11,760
390	11,447	30	8,533	11,378		
400	11,161	30½	8,393	11,191	13	10,920
450	9,921	34½	7,421	9,894	12	10,080
500	8,929	38	6,737	8,983	11	9,240
550	8,117	42	6,095	8,127	10	8,400
600	7,441	46	5,565	7,420	9	7,560

9. Linen, Jute, etc.—The count of linen yarn is based on the number of "cuts" of 300 yds. in 1 lb. The following table gives the counts of linen yarns by the weight in grains of 300 yds. (or "cut"):

300 Yards Weigh, Grains.	Number of Yarn.	300 Yards Weigh, Grains.	Number of Yarn.	300 Yards Weigh, Grains.	Number of Yarn.	300 Yards Weigh, Grains.	Number of Yarn.	300 Yards Weigh, Grains.	Number of Yarn.
100	70.00	300	23.33	490	14.29	680	10.29	1250	5.60
110	63.64	310	22.58	500	14.00	690	10.14	1300	5.38
120	58.33	320	21.87	510	13.73	700	10.00	1400	5.00
130	53.85	330	21.21	520	13.46	725	9.66	1500	4.67
140	50.00	340	20.59	530	13.21	750	9.33	1600	4.37
150	46.67	350	20.00	540	12.96	775	9.03	1700	4.12
160	43.75	360	19.44	550	12.73	800	8.75	1800	3.89
170	41.18	370	18.92	560	12.50	825	8.48	1900	3.68
180	38.89	380	18.42	570	12.28	850	8.24	2000	3.50
190	36.84	390	17.95	580	12.07	875	8.00	2250	3.11
200	35.00	400	17.50	590	11.86	900	7.78	2500	2.80
210	33.33	410	17.07	600	11.67	925	7.57	2750	2.55
220	31.82	420	16.67	610	11.48	950	7.37	3000	2.33
230	30.43	430	16.28	620	11.29	975	7.18	3250	2.15
240	29.17	440	15.91	630	11.11	1000	7.00	3500	2.00
250	28.00	450	15.56	640	10.94	1050	6.67	4000	1.75
260	26.92	460	15.22	650	10.77	1100	6.36	5000	1.40
270	25.93	470	14.89	660	10.61	1150	6.09	6000	1.17
280	25.00	480	14.58	670	10.45	1200	5.83	7000	1.00
290	24.14								

In determining the count of bleached linen yarns a loss for bleaching is allowed, as follows: full bleach, 20 percent; three-fourth bleach, 18 percent; half bleach, 15 percent.

Linen yarns are classified into hand-spun and machine-spun, and are also characterised as dry- or wet-spun. Dry-spun yarns are possessed of a greater degree of firmness, though finer numbers can be obtained by wet-spinning. Tow yarns are made from the waste of flax spinning and are readily distinguished from linen yarns by the numerous knots and shives which are present. Linen yarns are made from hackled flax while tow yarns are spun from carded flax waste. In Germany dry-spun yarns range from 10 to 30's, and wet-spun yarn up to 80's. Yarns as fine as 200 are spun in Belgium and Scotland. Tow yarns are dry-spun from 6 to 20, and wet-spun up to 35.

The count of linen yarn may also be obtained from the formula:

$$\text{Count} = \frac{\text{yards weighed}}{0.043 \times \text{weight in grains}}.$$

In England there is a difference in the method of numbering wet-spun and dry-spun flax yarns. In the former the bases is 1 lea of 300 yds.,

and the yarn size is the number of leas in 1 lb. weight, as given above. But in dry-spun flax (also for jute) the count is based on the spyndle of 14,400 yds. (48 cuts of 300 yds.), and the size or "grist" is the weight in pounds of 1 spyndle. In other words, in the case of wet-spun flax, the count increases as the yarn gets finer, the weight of 1 lb. being the fixed quantity. For dry-spun flax, however, the count increases as the yarn gets coarser, and the fixed quantity is the length of 14,400 yds.[1]

Jute yarns are numbered in the same manner as linen yarns, the basis also being the number of cuts (or leas) of 300 yds. in 1 lb. In Holland the count of jute yarns is given by the number of hectograms (0.22 lb.) in a length of 150 meters.

The count of jute yarns is also based on the weight in pounds per spindle of 14,400 yds. That is to say, if 14,400 yds. of the yarn weigh 8 lbs. the count is 8.

Hemp is reckoned on the same basis as jute.

Ramie yarns are numbered like chappe silk in Europe, that is to say, the count denotes the number of hanks of 1000 meters weighing 1 kilogram; hence a ramie yarn of 32 count would be equivalent to 20's in the cotton count. The same method of numbering prevails in America.

10. Comparison of Yarn Sizes.—The following table gives the comparison between the different English systems of yarn counts:

Name of System.	Unit Length and Name.	Count of Yarn Determined by
Cotton	840 yds. = 1 hank	Number of hanks in 1 lb.
Silk	840 yds. = 1 hank	Number of hanks in 1 lb.
Worsted	560 yds. = 1 hank	Number of hanks in 1 lb.
Woolen (Yorkshire)	256 yds. = 1 skein	Number of skeins in 1 lb.
Linen	300 yds. = 1 lea	Number of leas in 1 lb.
American cut	300 yds. = 1 cut	Number of cuts in 1 lb.
American run	100 yds. per ounce = 1 run	Number of runs × 16 in. 1 lb.
American grain	20 yds. per grain = 1 grain	Weight in grains of 20 yds.
Jute	14,400 yds. = 1 spyndle	Weight in pounds of 14,400 yds.

[1] The yarn table for wet-spun flax is:

90 ins. (once around the reel) = 1 thread = 2½ yds.
120 threads = 1 lea = 300 yds.
10 leas (English reeling) = 1 hank = 3000 yds.
12 leas (Scotch or Irish reeling) = 1 hank = 3600 yds.
20 English hanks = 1 bundle = 60,000 yds.
16⅔ Scotch or Irish hanks = 1 bundle = 60,000 yds.

For dry-spun flax (and jute):

90 ins. (once around the reel) = 1 thread = 2½ yds.
120 threads = 1 cut (lea) = 300 yds.
2 cuts = 1 heer = 600 yds.
12 cuts 1 hank (hasp) = 3600 yds.
48 cuts or 4 hanks = 1 spyndle = 14,400 yds.

Silk in the Gum, 1000 Yards per Skein.		Silk, Boiled, Half Skeins, 500 Yards.		Cotton (Singles) and Spun Silk, 840 Yards per Hank.		Yards.	Worsted (Singles), 560 Yards per Hank.		Woolen (Singles), 1200 Yards per Run.		Linen (Singles), 300 Yards per Lea (or Woolen by Cuts).	
Drams.	Yards per Pound.	Drams.	Yards per Pound.	No.	Yards per Pound.		No.	Yards per Pound.	Runs.	Yards per Pound.	Leas or Cuts.	Yards per Pound.
....	.....	.....	.....	..	.....	300	..	.....	...	.....	1	300
....	.....	.....	.....	..	.....	560	1	560	...	.....	2	600
....	.....	.....	.....	1	840	840	..	.....	...	.....	...	.....
....	.....	.....	.....	..	.....	1,000	2	1,120	...	.....	3	900
....	.....	.....	.....	2	1,680	1,600	3	1,680	1	1,600	5	1,500
....	.....	64	2,000	3	2,520	2,000	4	2,240	1¼	2,000	7	2,100
....	.....	42¾	2,994	4	3,360	3,000	5	2,800	2	3,200	10	3,000
....	.....	32	4,000	5	4,200	4,000	7	3,920	2½	4,000	13	3,900
....	.....	25½	5,019	6	5,040	5,000	9	5,040	3	4,800	17	5,100
....	.....	21½	6,024	7	5,880	6,000	11	6,160	3¾	6,000	20	6,000
....	.....	18¼	7,014	8	6,720	7,000	12	6,720	4½	7,200	23	6,900
....	.....	16	8,000	10	8,400	8,000	14	7,840	5	8,000	27	8,100
....	.....	14¾	8,678	11	9,240	9,000	16	8,960	5½	8,800	30	9,000
....	.....	12¾	10,039	12	10,080	10,000	18	10,080	6¼	10,000	33	9,900
....	.....	11¾	10,894	13	10,920	11,000	20	11,200	7	11,200	37	11,100
....	.....	10½	12,190	14	11,760	12,000	21	11,760	7½	12,000	40	12,000
....	.....	9¾	13,128	16	13,440	13,000	23	12,880	8	12,800	43	12,900
....	.....	9¼	13,838	17	14,280	14,000	25	14,000	8¾	14,000	47	14,100
....	.....	8½	15,059	18	15,120	15,000	27	15,120	9½	15,200	50	15,000
....	.....	8	16,000	19	15,960	16,000	29	16,240	10	16,000	53	15,900
....	.....	7½	17,067	20	16,800	17,000	30	16,800	10¾	16,800	57	17,100
....	.....	7	18,286	21	17,640	18,000	32	17,920	11¼	18,000	60	18,000
....	.....	6¾	18,963	23	19,320	19,000	34	19,040	12	19,200	63	18,900
....	.....	6½	19,692	24	20,160	20,000	36	20,160	12½	20,000	67	20,100
....	.....	5¾	22,261	26	21,840	22,000	40	22,400	14	22,400	74	22,200
10½	24,381	5¼	24,38¹	28	23,520	24,000	42	23,520	15	24,000	80	24,000
9¾	26,256	5	25,600	30	25,200	26,000	46	25,760	16	25,600	86	25,800
9¼	27,676	4¾	28,444	34	28,560	28,000	50	28,000	18	28,800	94	28,200
8¾	30,118	4½	30,118	36	30,240	30,000	54	30,240	19	30,400	100	30,000
8	32,000	4	32,000	38	31,920	32,000	58	32,480	20	32,000	106	31,800
7½	34,133	3¾	34,133	40	33,600	34,000	60	33,600	21	33,600	114	34,200
7	36,571	3½	36,571	42	35,280	36,000	64	35,840	22	35,200	120	36,000
6¾	37,926	.....	.....	46	38,640	38,000	68	38,080	24	38,400	126	37,800
6½	39,385	3¼	39,385	48	40,330	40,000	72	40,320	25	40,000	134	40,200
6	42,667	3	42,667	50	42,000	42,000	76	42,560	26	41,600	140	42,000
5¾	44,522	.....	.....	52	43,680	44,000	78	43,680	28	44,800	146	43,800
5½	46,545	2¾	46,545	54	45,360	46,000	82	45,920	29	46,400	154	46,200
5¼	48,762	.....	.....	58	48,720	48,000	86	48,160	30	48,000	160	48,000
5	51,200	2½	51,200	60	50,400	50,000	90	50,400	31	49,600	166	49,800
4¾	52,512	.....	.....	62	52,080	52,000	92	51,520	32	51,200	174	52,200
4½	53,895	.....	.....	64	53,760	54,000	96	53,760	34	54,400	180	54,000
4¼	55,351	2¼	56,889	66	55,440	56,000	100	56,000	35	56,000	186	55,800
4⅛	58,514	.....	.....	70	58,800	58,000	104	58,240	36	57,600	194	58,200
4¼	60,235	.....	.....	72	60,480	60,000	108	60,480	38	60,800	200	60,000
4⅛	62,060	.....	.....	74	62,160	62,000	110	61,600	39	62,400	206	61,800
4	64,000	2	64,000	76	63,840	64,000	114	63,840	40	64,000	214	64,200
3¾	66,065			78	65,520	66,000	118	66,080	41	65,600	220	66,000
3½	68,267	Silk Filatures, in Gum, 1000 Yards per Skein.		80	67,200	68,000	122	68,320	42	67,200	226	67,800
3⅜	70,621			84	70,560	70,000	126	70,560	44	70,400	234	70,200
....	.....			86	72,240	72,000	128	71,680	45	72,000	240	72,000
3¼	73,142			88	73,920	74,000	132	73,920	46	73,600	246	73,800
3⅛	75,852	Deniers.	Yards per Lb.	90	75,600	76,000	136	76,160	48	76,800	254	76,200
3¼	78,769			92	77,280	78,000	140	78,400	49	78,400	260	78,000
....	.....	54/56	79,125	96	80,640	80,000	142	79,520	50	80,000	266	79,800
3⅛	81,920	52/54	82,125	98	82,320	82,000	146	81,760	51	81,600	274	82,200
....	.....	.....	.....	100	84,000	84,000	150	84,000	52	83,200	280	84,000
3	85,333	50/52	85,333	102	85,680	86,000	154	86,240	54	86,400	286	85,800
....	.....	48/50	88,750	104	87,360	88,000	158	88,480	55	88,000	294	88,200
2⅞	89,043	.....	.....	108	90,720	90,000	160	89,600	56	89,600	300	90,000
2¾	93,091	46/48	92,666	110	92,400	92,000	164	91,840	58	92,800	306	91,800
2⅝	97,524	44/46	96,750	114	95,760	96,000	172	96,320	60	96,000	320	96,000
2½	102,400	42/44	101,250	120	100,800	100,000	180	100,800	62	99,200	330	99,000
2⅜	107,789	40/42	106,125	130	109,200	110,000	200	112,000	69	110,400	370	111,000
2¼	120,471	36/38	117,625	142	119,280	120,000	210	117,600	75	120,000	400	120,000
2	128,000	32/34	132,000	154	129,360	130,000	230	128,800	80	128,000	430	129,000
1⅞	136,533	30/32	140,000	166	139,440	140,000	250	140,000	90	144,000	470	141,000
1¾	146,286	28/30	150,000	178	149,520	150,000						
1⅝	170,667	24/26	174,000	200	168,000	170,000						
1⅝	186,182	22/24	189,250	230	193,200	190,000						
1½	204,800	20/22	207,250	240	201,600	200,000						
1⅜	227,556	18/20	229,000	270	226,800	225,000						
1	256,000	16/18	256,000	300	252,000	250,000						
⅞	292,571	14/16	290,000	..	.....	300,000						
¾	341,333	12/14	334,750	..	.....	350,000						
⅝	409,600	10/12	395,666	..	.....	400,000						
½	512,000	8/10	483,500	..	.....	500,000						
⅜	682,667	6/8	621,750	..	.....	600,000						
....	.....	4/6	870,500	..	.....	800,000						
¼	1,024,000					1,000,000						

2-ply, 3-ply and 4-ply Cotton, Worsted, Woolen and Linen Yarns, have respectively ½, ⅓ and ¼ the number of hanks per pound and yardage their counts or numbers indicate.

Spun Silk Yarns, however, in 2-ply, 3-ply, etc., have the number of hanks per pound and yardage their counts indicate, and are written 20/2, 30/2, 20/3, 30/3, etc.

Corresponding counts and yardage are on the same line running across the table.

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